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Personal Equipment and Clothing Correction Factors for the Australian Army: A Pilot Survey

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Land Division
Defence Science and Technology Organisation

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ABSTRACT

The Australian Warfighter Anthropometry Survey (AWAS), as per traditional anthropometric protocol, gathered data from semi-nude subjects. It is important, when required, to apply a clothing correction factor to these semi-nude statistics to ensure a more realistic representation of the encumbered human. Data from a meta-analysis of current personal equipment and clothing corrections (PECCFs) data identified the need for an encumbered anthropometric survey applicable to the ADF. The aim of the pilot survey was two-fold. Firstly, to provide interim PECCFs for use in design projects and secondly, to develop, test and refine a reliable, valid methodology for use in future surveys. The methodology proved to be largely successful with the majority of measures providing reliable results although there were limitations imposed by a small sample size. A number of recommendations were produced relating to further areas of work to further analyse and refine future surveys.

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Executive Summary

The Australian Warfighter Anthropometry Survey (AWAS), as per traditional anthropometric protocol, gathered data from semi-nude subjects. It is important, when required, to apply a clothing correction factor to these semi-nude statistics to ensure a more realistic representation of the encumbered human. Within the Australian Defence Force (ADF) such corrections do not just apply to items of clothing but also to other personal equipment items including ballistic and fragmentation protection, load carriage rigs, hydration packs and ammunition belts. The combination of the correction factors and the range of AWAS anthropometric data allow the space claim requirements of vehicle occupants to be characterised and utilised in ergonomic assessments. Despite the importance of personal equipment and clothing corrections (PECCFs) there is limited data available, and the validity of applying the data to represent ADF specific items is questionable.

Data from a meta-analysis of current PECCF data identified the need for an encumbered anthropometric survey applicable to the ADF. Whereas the methods and techniques for gathering semi-nude anthropometric data are well established, methods and techniques for encumbered anthropometry are still being developed and tested and, as such, a pilot survey was required. The aim of the pilot survey was two-fold. Firstly, to provide interim PECCFs for use in design projects and secondly, to develop, test and refine a reliable, valid methodology for use in future surveys.

Data from the meta-analysis and an encumbered anthropometric working meeting, attended by other Technical Cooperation Panel Nations (TTCP) at Natick Soldier Research, Development and Engineering Centre (NSRDEC), were used to develop the methodology for the pilot survey. The methodology included obtaining both manual and 3D scanned images of the participants in different Solider Combat Ensemble (SCE) conditions.

The methodology proved to be largely successful with the majority of measures providing reliable results although there were limitations imposed by a small sample size. A number of recommendations were produced relating to further areas of work to further analyse and refine future surveys. Recommendations were also produced to improve the efficiency and reliability of the method for future surveys.

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Acronyms and Abbreviations

ADF	Australian Defence Force
ADHREC	Australian Defence Human Research and Ethics Committee
AWAS	Australian Warfighter Anthropometry Survey
CE	Combat Engineer
CI	Confidence Interval
CV	Coefficient of Variation
CWC	Cold Weather Clothing
CVC	Combat Vehicle Crewman
DCC	Dismounted Close Combatant
DHM	Digital Human Manikin/Modelling
DSTO	Defence Science and Technology Organisation
DW	Diggerworks
ECH	Enhanced Combat Helmet
FPS	Functional Performance Specification
HSI	Human Systems Integration
ISO	International Standards Organisation
LD	Land Division
L400	Land 400
MBITR	Multiband Inter/Intra Team Radio
N	Number of survey participants
NSRDEC	Natick Solider Research and Development Engineering Centre
NVGs	Night Vision Goggles
OCU	Operational Combat Uniform
PECCF	Personal Equipment and Clothing Correction Factor(s)
SCE	Soldier Combat Ensemble
SD	Standard Deviation
SMSPO	Soldier Modernisation Systems Program Office
TBAS	Tiered Body Armour System
TEM	Technical Error of Measurement
TP	Technical Panel
TTCP	The Technical Cooperation Panel
VAV	Variable Average Value

1. Introduction

1.1 Background

Anthropometry is the measurement of the human body. These measurements are required to feed into designs to ensure that equipment, clothing, work spaces and environments, such as vehicles, are adequate for all potential users to fit and be able to perform their required tasks without detriment to their health or task performance.

Prior to 2010 there was no up-to-date anthropometric data for the Australian Defence Force (ADF) Army population. In early 2010, based on a requirement by the Soldier Modernisation Systems Project Office (SMPSO), Defence Science and Technology Organisation (DSTO) Land Division (LD) surveyed 417 army members at 1 BDE in Darwin. This became the Australian Warfighter Anthropometry Survey (AWAS) pilot study and provided data, not only for the SMSPO requirement, but for other Functional Performance Specifications (FPS). Due to the requirement for a larger sample size and a balance of Corps and Trades to the wider ADF Corp/Trade profile than was available in 1 BDE, a full scale survey commenced in 2011 and was completed at the end of 2012. The data will provide the basis for an anthropometric DEF(AUST) which will be produced in 2014 and will provide an anthropometric data set for the Army.

Traditional anthropometric data are typically gathered from semi-nude subjects; therefore it is important, when required, to apply a clothing correction factor which represents additional volume and dimensions of wearing personal equipment. Such corrections, referred to as Personal Equipment and Clothing Correction Factors (PECCF), do not just apply to items of clothing but also to other items including ballistic and fragmentation protection, load carriage rigs, hydration packs and ammunition pouches. When designing platforms, such a vehicles, it is important to use measures which represent the clothed/equipped user which, in the case of the Army is the encumbered warfighter, to ensure adequate fit, operation and egress from a platform. This area is also known as 'encumbered anthropometry' and, despite the importance of utilising such PECCFs, there is no specific PECCF for the ADF.

1.2 Meta-Analysis

1.2.1 Introduction

A meta-analysis of current equipment and clothing correction factor data and its' relevance to the ADF was conducted by LD in 2011. The meta-analysis identified a number of encumbered anthropometric datasets which are presented in Table 1.

Table 1: Encumbered Anthropometric Datasets

No.	Title	Authors/ Organisation/ Owners	Year	Country
1	Human Scale One/Two/Three [1]	Niels Diffrient, Alvin R. Tilley and Joan Bardagy	1974	Unknown
2	Effects of Protective Equipment on Anthropometric Measurements and Functional Limitations [2]	Carrier, R, & Meunier, P	1996	Canada
3	The Effects of Multilayered Military Clothing Ensembles on Body Size: A Pilot Study U.S Army Solider and Biological Chemical Command Soldier Systems Centre [3]	Paquette, S.P., Case, H.W, Annis., J.F., Mayfield, T.L., Kristensen, S. and Mountjoy, D.N	1999	USA
4	The Measure of Man and Woman: Human Factors in Design *John Wiley & Sons, Inc. 2002* [4]	Dreyfuss, H. & Tilley, A.R	2002	Unknown
5	Military Standard 1472F (2003) Human Engineering [5]	Department of Defense, USA	2003	USA
6	Bodyspace: Anthropometry, Ergonomics and the Design of Work *Taylor & Francis* [6]	Pheasant, S. & Haslegrave, C.M.	2006	UK
7	Dutch Anthropometry for Vehicle Design and Evaluation *TNO-DV 2008 A211* [7]	Oudenhuijzen, A.J.K, Zehner, G, and Hudson, J	2008	Netherlands
8	Defence Standard 250, Issue 1 Human Factors for Designers of Systems, Part 3: Technical Guidance. Section 9: People Characteristics [8]	Ministry of Defence, UK	2008	UK
9	Pilot Study of Firefighter Three-Dimensional Anthropometry to Improve Seatbelt Safety [9]	National Institute of Standards and Technology, U.S. Department of Commerce	2008	USA

Each method and resulting dataset was reviewed for applicability to ADF use. Some of the datasets were more relevant to the ADF than others, for example DEFSTAN 00-25 [8] and Oudenhuizen et al [7], provide PECCFs which are related to army roles. DEFSTAN 00-25 provides twelve correction factors for 'combat' and 'cold weather' ensembles and Oudenhuizen et al focuses on anthropometry in military vehicle design with eight correction factors.

However, the meta-analysis identified that, all the datasets in Table 1 have one or more shortcoming(s) which meant that they are not able to be applied to the AWAS data for use in ADF projects. These shortcomings relate to the following areas:

- sample size and sex,
- configuration and applicability to the ADF, and
- measurement method and validity.

1.2.2 Shortcoming I: Sample Size and Sex

Samples sizes for traditional anthropometric data are collected based on a power analysis of any given measure and the desired accuracy (typically 1% accuracy and 95% confidence). In general terms, the more variable a measure, such as waist circumference, then the higher the sample size required to achieve the desired accuracy. The overall variability of encumbered anthropometric data are not known, hence surveys with extremely low sample sizes may be reporting inaccurate results.

The sample sizes used to derive the data presented in both DEF-STAN 00-25 [8] and MIL-STD 1472F [5] are not specified. The TNO Military Vehicle study [7] used five subjects and only one study, Paquette *et al* [3], measured female subjects; all other surveys only measured male subjects. The sample sizes, where they are reported, are low and, given the other shortcomings identified in the meta-analysis cannot be used for ADF purposes.

1.2.3 Shortcoming II: Configuration and Applicability to the ADF

There were two key problems with the ensembles documented in the literature. Firstly, on a number of occasions the description of the ensembles was lacking and so it was not possible to compare to the ADF clothing and equipment. Secondly, even when adequate information on the ensembles used was provided, a comparison determined that they were not comparable to ADF clothing and equipment. Therefore, it is not feasible to apply any of the encumbered data presented in the literature to the AWAS data as one cannot be sure that it would represent an Australian Soldier Combat Ensemble (SCE).

1.2.4 Shortcoming III: Measurement Method and Validity

When semi-nude anthropometric measurements are taken, anatomical landmarks are located either visually or through palpation and provide reference points for the different measures. When clothing and equipment are added then it becomes difficult and, frequently, impossible, to locate these landmarks through either visual identification or palpation. A number of different methods of locating landmarks have been trialled in the various studies. These methods include affixing ball bearings to the landmarks on the semi-nude subject and then palpating for the ball bearings through the clothing/equipment [3]. A variation on this was to attach magnetic markers to the semi-nude subject and use a magnet to identify the area of the landmarks through the clothing/equipment. Another method took the height of circumferences, breadths and girths when semi-nude and using the heights to locate the area of the landmark when clothed/equipped. There are pros and cons to each method but the issue remains that a consistent way of taking encumbered measures had not been identified and validated.

1.2.5 Conclusion

Based on the shortcomings identified in the literature available, the conclusion of the meta-analysis was that there was no data applicable to the ADF and that methods used and lessons learnt from the previous studies should be used to develop an ADF specific encumbered anthropometric pilot survey.

1.3 Pilot Survey Aims

The aims of the pilot survey were three-fold. Firstly, to provide PECCFs for immediate application, secondly, to assess the feasibility of using 3D scanning technology to provide PECCFs and thirdly, to develop a robust methodology for use in future surveys.

2. Method

2.1 Considerations

There were a number of considerations to be addressed when designing the method for collecting and analysing the encumbered data:

1. sample size;
2. quality of clothed/equipped 3D scans and the ability to extract measurements from the scans;
3. time taken for transferring landmarks, taking manual measurements and scanning;
4. equipment requirements for taking manual measurements;
5. postures;
6. measurement of features such as knee and elbow pads; and
7. reliability and validity of the derived measures.

2.2 Methodology

2.2.1 Development

The methodology was developed based on the information gathered from the meta-analysis and also from discussions held at the first Encumbered Anthropometry Working Meeting hosted by The Technical Cooperation Program (TTCP), Human Resources and Performance (HUM) Group Technical Panel (TP) 15, Human Systems Integration (HSI) – Land and Natick Soldier, Research, Development, and Engineering Center (NSRDEC), HSI and Sciences Division.

2.2.2 Sample

It was important to include both male and female subjects in the pilot survey as females are no longer exempt from front line roles within the ADF. An added objective of the pilot survey was to identify if the PECCFs were different for males and females.

Ten subjects were used in the pilot survey with an equal number of male and female subjects.

2.2.3 Soldier Combat Ensemble

Within the ADF there are multiple roles which require different clothing and equipment ensembles. Land 400 (L400) directed LD to provide an anthropometric dataset for the L400 FPS. In order to match the requirements of the FPS, two roles were considered; Dismounted Close Combatant (DCC) and Vehicle Crew. For each of these roles, data were collected for the regular combat and the Cold Weather Clothing (CWC) ensembles. The 'regular' ensemble is referred to as SCE One, and the CWC ensemble is SCE Two. Given the two roles and the two ensembles, there are a total of four conditions to be assessed;

1. DCC (SCE One).
2. Vehicle Crew (SCE One).
3. DCC (SCE Two).
4. Vehicle Crew (SCE Two).

The difference between the DCC and the Vehicle Crew ensembles is that the DCC wears a Tier 2 Tiered Body Armour System (TBAS) with multiple pouches and an Enhanced Combat Helmet (ECH) (the current Tier 2 helmet), whereas the Vehicle Crew will wear a Tier 3 TBAS, with minimal or no pouches, and a Combat Vehicle Crewman (CVC) helmet with liner to allow communications. The difference between the regular and the CWC ensembles is the addition of the CWC jacket and pants, and the use of CWC gloves rather than patrol gloves. The 'tiers' of body armour and helmet relate to a structured approach adopted by Army whereby a range of SCE capability solutions are required to meet the need(s) of potential users.

The configuration of the equipment needs to be representative of real usage. Within the larger role of 'Tier 2 Combatant' there are a number of more specific roles which include a Combat Engineer (CE), Combat Medic, Signaller and Marksman. There is currently no definitive configuration management for these roles as the different roles have requirements to carry different items of equipment and each soldier will carry their equipment in different locations on their body armour and in their packs. Furthermore, with the new spiral development process adopted by Army, which provides adaptive acquisition, the configurations are likely to change on a more frequent basis. This emphasises the requirement to have a 'best fit' configuration and to provide a means to easily and quickly up-date the encumbered anthropometric dataset to represent changes in equipment borne on the soldier.

Discussions with Diggerworks (DW) were held to identify a representative configuration for both the DCC and Vehicle Crew ensembles. In order to ensure the measurements, which include the pouches, are representative, it was important to insert replica items which characterise the bulk of the real items. DW has a series of plastic and wooden items such as magazines, Multiband Inter/Intra Team Radio (MBITR) and hand grenades which are the same size as the real items. These replicas were used and inserted into the relevant pouches.

A list of all items of clothing and equipment which were worn by each subject, the number of each item used, the replica item inserted and any additional information, i.e. pockets to be empty and closed, is presented in Appendix A. Examples of all four SCE conditions are presented in Appendix B.

2.2.4 Key Measurements

The AWAS dataset comprises 83 measurements. Many discrete semi-nude measures are required as they are used to design clothing and equipment to ensure they fit all user body shapes and sizes. Encumbered anthropometric data are required to determine occupant packaging or space claims and, therefore, not all the measures are required. For example; shoulder length is important for the design of clothing but there is not currently any use for this measure when the user is clothed/equipped. It was important to identify the measures which may require PECCFs. The following categories of assessment were identified as requiring some encumbered anthropometric measurements:

1. Digital Human Manikin (DHM) production; i.e. the measures which are required for Jack or RAMSIS manikin development;
2. Fit; i.e. the measures required to identify the size a vehicle seat needs to be for occupants to be accommodated;
3. Clearance; i.e. the measure required to determine the minimum depth a hatch can be to allow user access;
4. Workstation and pedal operation; i.e. the measures which are required to determine the minimum height a pedal can be from the floor to allow drivers to adequately reach and operate the pedal; and
5. Access in gloves; i.e. the smallest size a trigger guard can be to fit a finger wearing gloves.

Reach was also identified as an area which required encumbered anthropometric data. A number of reach measures were originally included in the set of measures to be obtained but it was concluded that reach and range of motion data should be collected in a separate study as there are additional considerations and measurement methods to consider (Recommendation 2d).

Table 2 presents the key measurements which were identified at the outset of the study as requiring PECCF data and the relevant assessment category.

Table 2: Key Encumbered Anthropometric Measures

Measure	AWAS I.D.	Category
STANDING MEASURES		
Stature	M38	Clearance
Weight	M40	Clearance
Head Circumference	M28	Clearance and Fit
Head Breadth	M41	Clearance and Fit, DHM
Head Length	M42	Clearance and Fit, DHM
Acromion Height	M03	Clearance
Chest Circumference	M33	Clearance and Fit
Chest Breadth	M19	Clearance and Fit
Chest Depth	M20	Clearance and Fit
Waist Circumference	M35	Fit
Buttock Circumference	M36	Fit
Crotch Height	M08	Clearance and Fit
Hand Circumference	M64	Access in gloves
Hand Breadth	M65	Access in gloves
Hand Length	M66	Access in gloves, DHM
Hand Thickness	-	Access in gloves, DHM
Ankle Height	M84	Fit, DHM
Foot Breadth, Horizontal	M27	Pedal Operation, DHM
Foot Length	M71	Pedal Operation, DHM
Ball of Foot Length	M72	Pedal Operation
SEATED MEASURES		
Sitting Height	M39	Clearance and Fit, DHM
Sitting Eye Height	M09	Clearance and Fit, DHM
Acromion Height, Sitting	M10	Fit, DHM
Bideltoid Breadth	M18	Clearance and Fit, DHM
Forearm-Forearm Breadth	M22	Clearance and Fit
Elbow Rest Height	M11	Fit, DHM
Abdominal Extension Depth, Sitting	M23	Clearance and Fit, DHM
Hip Breadth, Sitting	M24	Fit
Thigh Clearance	M12	Clearance and Fit, DHM
Knee Height, Sitting	M13	Fit, DHM
Popliteal Height	M14	Fit, DHM
Buttock-Knee Length	M25	Clearance and Fit, DHM
Buttock-Popliteal Length	M26	Clearance and Fit

2.2.5 Postures and Measurement Technique

As the PECCF data is added to the semi-nude anthropometric measurement it is important that measurements are taken in the same posture. Anthropometric measurements are traditionally taken in an anthropometric standing posture, a scanning standing posture

and a seated anthropometric posture as defined in the ADF Anthropometric Survey (2012): Landmarking and Measurement Manual [10].

The reliability of different measures is dependent on the method used to obtain the measure. Work was conducted by the University of South Australia which determined whether or not the semi-nude AWAS measurements should be taken manually or by 3D scan to provide the most reliable measurements [11]. Manual and scanned measures provide slightly different results for the same measure due to the levels of accuracy afforded by the different measures and so all semi-nude measures in the pilot survey were taken by the same method as they were in AWAS. This allowed for comparison of the semi-nude measurements to the AWAS data, without the potential bias introduced by adopting a different measurement method.

Although the semi-nude measures were taken in the same way in the pilot survey as they were in AWAS, there are other factors to consider when identifying the best method to take the encumbered measures. The main issue was the compacting of the clothing. In terms of efficiency of space, it is not beneficial for a design to over-estimate the amount of clearance required to fit users. If measures are taken without compression of the clothing the results will show an over estimated measure. It is more realistic to take the measures on compressed clothing. This can be achieved by applying tension to the measuring tape or callipers. However, taking measures manually with tape/callipers increases the amount of time a subject is required to be dressed in the ensemble and maintaining a specific posture. Furthermore, to aid the collection of reliable data, it is advisable to have the subject wearing the SCE and maintaining specific postures for the minimal amount of time necessary. Measure such as Bideltoid Breadth and Chest Depth require compression of clothing but others such as Helmet Circumference and Ankle Height do not require compression, as the landmark is not affected by excess clothing.

The solution, therefore, was to take all of the measure which require clothing compression manually and take all others using the 3D scanner. This approach ensures that realistic measures are taken by compressing the clothing, where required, and using the scanner for the measures which do not require compression, this is a more pragmatic and quicker approach to taking these measurements.

During the planning stage of the pilot survey, encumbered scans were taken and assessed to determine which measures could be extracted. As the top of the helmet and the boots are subject to occlusion, stature and feet measures were taken manually to achieve more accurate results. Measures which did not require manual compression are those where a height is required or where the posture adopted will pull the clothing tight and eliminate the need for further compression, i.e. bent elbows. Due to the thickness of the CWC no scans were taken and all measures were taken manually to allow for compression of the material. Table 3 presents the measurement method for each of the encumbered measures.

Table 3: Encumbered Measuring Techniques

Measure	Measurement Method (SCE 1)	Measurement Method (SCE 2)
Stature	Manual	Manual
Weight	Manual	Manual
Head Circumference	Scan	SCE 1 data
Head Breadth	Scan	SCE 1 data
Head Length	Scan	SCE 1 data
Acromion Height	Scan	Manual
Chest Circumference	Manual	Manual
Chest Breadth	Manual	Manual
Chest Depth	Manual	Manual
Waist Circumference	Manual	Manual
Buttock Circumference	Manual	Manual
Crotch Height	Manual	Manual
Hand Circumference	Manual	SCE 1 data
Hand Breadth	Manual	SCE 1 data
Hand Length	Manual	SCE 1 data
Hand Thickness	Manual	Manual
Ankle Height	Scan	Manual
Foot Breadth, Horizontal	Manual	Manual
Foot Length	Manual	Manual
Ball of Foot Length	Manual	Manual
Sitting Height	Manual	Manual
Sitting Eye Height	Manual	Manual
Acromion Height, Sitting	Scan	Manual
Bideltoid Breadth	Manual	Manual
Forearm-Forearm Breadth	Manual	Manual
Elbow Rest Height	Scan	Manual
Abdominal Extension Depth, Sitting	Manual	Manual
Hip Breadth, Sitting	Manual	Manual
Thigh Clearance	Manual	Manual
Knee Height, Sitting	Manual	Manual
Popliteal Height	Manual	Manual
Buttock-Knee Length	Manual	Manual
Buttock-Popliteal Length	Manual	Manual

The whole-body laser scanner used for the pilot survey was the Vitus XXL (*Human Solutions, Kaiserslautern, Germany)* as shown in Figure 1.

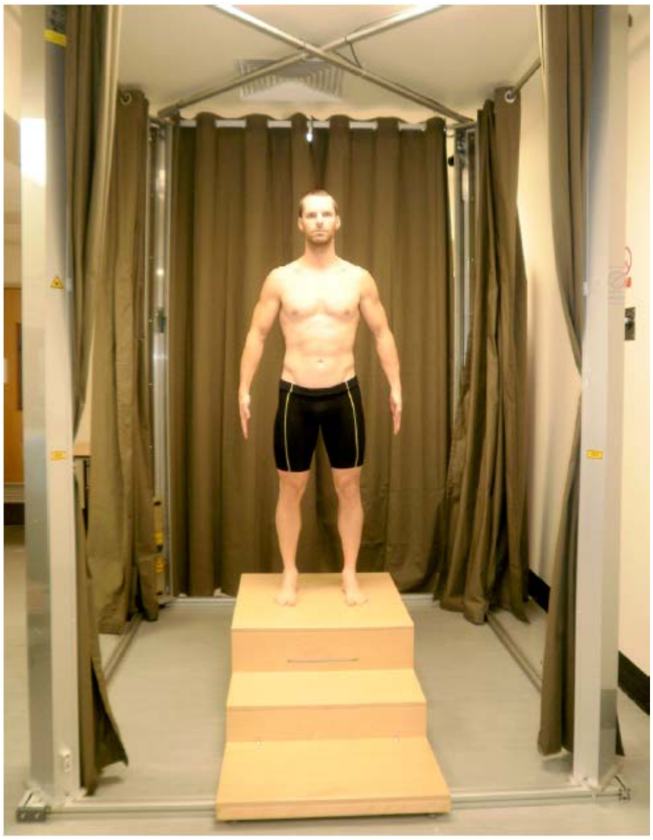

Figure 1: Vitus XXL Whole-Body Laser Scanner

2.2.6 Landmarking Protocol

One of the key issues facing the reliable extraction of encumbered anthropometric data is the transference of anatomical landmarks to external points on the clothing/equipment. When subjects are semi-nude it is easy to palpate or visually identify the anatomical landmarks which are required as reference points for each anthropometric measure. When clothing and equipment are added to a subject the ability to locate these landmarks is dramatically reduced and, in many cases, eliminated.

As the measures are manually extracted from the 3D scan there is still a requirement to locate and indicate landmarks. In the AWAS landmarks were identified using a sticker and/or a prism as shown in Figure 2 [10], and this was adopted for the semi-nude measures taken in the pilot survey. The sticker with a hole in the middle and the prism were identified by University of South Australia as optimal in aiding landmark identification.

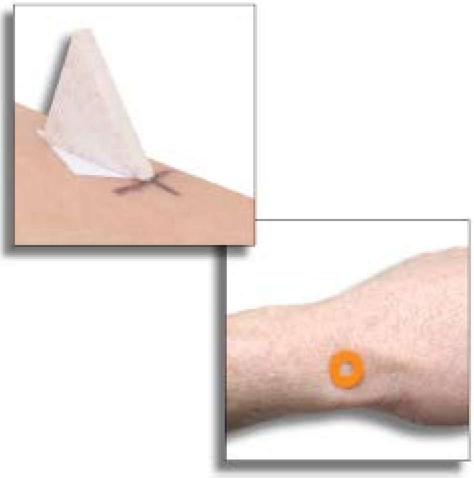

Figure 2: Landmarkers

The meta-analysis identified that previous surveys had used different methods to try and reliably transfer landmarks from the semi-nude condition to the encumbered position. The most reliable method appeared to be that applied by Paquette *et al* [3] where the heights of landmarks were taken from the semi-nude subject and then used to identify the landmark on the clothed/equipped subject. Consideration of the encumbered measures to be taken as part of this pilot study identified that only ten landmarks would be required (for both manual and scanned measures) as all other measures used 'bounding' landmarks which can be visually identified. The term 'bounding measures' is applied in this survey to describe those measures which use the most posterior/anterior or most lateral points to obtain a measure. Good examples of these measures are Hip Breadth, where the measure is taken from the maximum breadth of the seated subject at the hip or thigh (whichever is larger), and Buttock-Knee Length which is the horizontal distance between the clothed Buttock Point Posterior (point of maximal protrusion of the right buttock) to the Knee Point Anterior (most protruding point of the right kneecap of the seated subject). Because the encumbered anthropometric measures that were identified for this pilot survey related to occupant packaging and space claims, most of the measures are bounding and so the requirement to locate landmarks which are not bounding is reduced.

The definition of an anthropometric measure defines how the measure is to be taken. Some encumbered measures required different definitions to their counterpart AWAS semi-nude measures. The difference in definition can be as simple as changing the definition from 'distance to Acromion, Right' to 'distance to <u>clothed</u> Acromion, Right'. However, as the interest in encumbered anthropometry for the ADF is related to occupant packaging and space claim, a number of the encumbered measurement definitions, and landmarks, have been amended to represent this. For example: Chest Depth for females has changed from 'the horizontal distance between the <u>Bustpoint, Right female and point on the back at the same level</u>' to 'the horizontal distance between the most <u>anterior and posterior point of the clothing/equipment at approximate chest level</u>'. The reason for this change is because the measurement at the Bustpoint, Right (when clothed and equipped) may not represent

the maximal measurement in the chest area. The maximal measurement is required to ensure that users fit into the space which is being designed.

The semi-nude definition, taken from the ADF Anthropometry Survey (2012): Landmarking and Measurement Manual [10], and the corresponding encumbered anthropometric definition are presented in Table 4. Pictures of the encumbered anthropometric definitions are presented in Appendix C.

Table 4: Anthropometric Measurement Definitions

Measure		Semi-Nude Definition	Encumbered Definition
EM01	Stature	The vertical distance between the standing surface and the Top of the Head landmark (M38).	The vertical distance between the standing surface and the Top of the Helmet.
EM02	Weight	The mass of the subject recorded to the nearest 0.1 kg (M40).	The mass of the subject wearing clothing and equipment to the nearest 0.1 kg.
EM03	Head/Helmet Circumference	The maximum horizontal circumference of the head above the supraorbital ridges and ears, at the level of Glabella (M28).	The circumference of the helmet is calculated by πd where 'd' is the Helmet Breadth (EM04) or Length, (EM05) whichever is larger.
EM04	Head/Helmet Breadth	The point-to-point distance between the digitally-extracted Head Breadth Marker, Left and Head Breadth Marker, Right landmarks (M41).	The point-to-point distance between the most Left (lateral) and Right (lateral) points on the Helmet.
EM05	Head/Helmet Length	The point-to-point distance between the digitally-extracted Glabella and Opisthocranion landmarks (M42).	The point-to-point distance between the most anterior point on the front of the Helmet and the point on the back of the Helmet at the same level.
EM06	Acromion Height	Standing surface to Acromion, Right (M03).	Standing surface to clothed Acromion, Right.
EM07	Chest Circumference	The circumference of the chest at the height of the Bustpoint, Right (females) or Thelion, Right (males) (M33).	The circumference of the clothed chest at the height of the point of the anterior Chest Depth measurement (EM10) following the most posterior and distal points of the clothing/equipment.
EM08	Chest Breadth	The maximum horizontal breadth at the height of Bustpoint, Right (females) or Thelion, Right (males) (M19).	The maximum horizontal breadth at the height of the compressed under-arm seam.

Measure		Semi-Nude Definition	Encumbered Definition
EM09	Chest Depth	The horizontal distance between the Bustpoint, Right (females) and Thelion, Right (males), and point on the back at the same level (M20).	The horizontal distance between the most anterior point of clothing/equipment at approximate chest level.
EM10	Waist Circumference	The circumference of the torso at the height of the Waist (Omphalion) Anterior (M35).	The circumference of the clothed waist at the most anterior point of clothing/equipment at the point of the Abdominal Extension Depth (EM27) and the point on the back at the same level.
EM11	Buttock Circumference	The horizontal circumference of the torso at the height of the Buttock Point, Posterior (M36).	The horizontal circumference of the torso at the height of the clothed Buttock Point, posterior.
EM12	Crotch Height	Standing surface to Crotch (M08).	Standing surface to crotch seam of pants.
EM13	Hand Circumference	The circumference around the hand that passes over the digital Metacarpale, II and Metacarpale, V landmarks (M64).	The circumference around the hand that passes over the clothed Metacarpale, II and the clothed Metacarpale, V landmarks.
EM14	Hand Breadth	The point-to-point distance between the digitally-extracted Metacarpale, II and Metacarpale, V landmarks (M65).	The distance between the clothed Metacarpale, II and the clothed Metacarpale, V landmarks.
EM15	Hand Length	The point-to-point distance between the digitally-extracted Centre Wrist Marker and Dactylion, III landmarks (M66).	The distance between the clothed Centre Wrist Marker and clothed Dactylion, III landmarks.
EM16	Hand Thickness	No semi-nude anthropometric measure.	The distance between the clothed lateral points of the clothed Metacarpale, II.
EM17	Ankle Height	The vertical distance between the standing surface and the digitally-extracted Lateral Malleolus landmark (M84).	The vertical distance between the standing surface and the clothed Lateral Malleolus landmark.
EM18	Foot Breadth, Horizontal	The maximum horizontal distance between the First Metatarsophalangeal Protrusion and the Fifth Metatarsophalangeal Protrusion (M27).	The maximum horizontal distance between the clothed First Metatarsophalangeal Protrusion and clothed the Fifth Metatarsophalangeal Protrusion at the distal edges of the sole of the boot.
EM19	Foot Length	The point-to-point distance between the digitally-extracted Acropodion and Pternion landmarks (M71).	The distance between the clothed Acropodion and the clothed Pternion landmarks at the most posterior and anterior edges of the sole of the boot.

Measure		Semi-Nude Definition	Encumbered Definition
EM20	Ball of Foot Length	The distance along a line between Acropodion and Pternion between the Pternion and intersection of a line drawn through the First Metatarsophalangeal Protrusion landmark perpendicular to the line between Acropodion and Pternion (M72).	The distance along a line between the clothed Acropodion and Pternion between the Pternion and intersection of a line drawn through the First Metatarsophalangeal Protrusion landmark perpendicular to the line between Acropodion and Pternion.
EM21	Sitting Height	The vertical distance between the sitting surface and Top of the Head (M39).	The vertical distance between the sitting surface and Top of the Helmet.
EM22	Acromion Height, Sitting	Sitting surface to Acromion, Right (M10).	Sitting surface to clothed Acromion, Right.
EM23	Bideltoid Breadth	The distance between the lateral margins of the upper arms on the deltoid muscles (M18).	The most lateral points on the clothed left and right upper arms. *Note that the breadth may not be taken directly on the deltoid but it is taken at the widest part as it is the largest distance which is of importance.*
EM24	Forearm-Forearm Breadth	The maximum horizontal distance between the most lateral points on the right and lateral left forearms (M22).	The maximum horizontal distance between the most lateral points on the clothed right and lateral left forearms (to the most distal point of the elbow pads).
EM25	Abdominal Extension Depth, Sitting	The horizontal distance between the Abdominal Point, Anterior, and point on the back at the same level (M23).	The horizontal distance between the most anterior point of clothing/equipment at approximate waist level, and the point on the back at the same level. *When wearing body armour the Abdominal Extension Depth point is the most anterior point and so the circumference, taken at this point, represents the largest possible circumference in the waist area.*
EM26	Hip Breadth	The maximum breadth of the seated subject at the hip or thigh, whichever is larger (M24).	The maximum breadth of the seated subject at the clothed hip or thigh, whichever is larger.
EM27	Thigh Clearance	Sitting surface to Thigh Point, Top (M12).	Sitting surface to clothed Thigh Point, Top.

Measure		Semi-Nude Definition	Encumbered Definition
EM28	Knee Height, Sitting	Footrest surface to Suprapatella (M13).	Footrest surface to superior point of clothed knee or top of the knee pad.
EM29	Popliteal Height	Footrest surface to the Dorsal Juncture of Calf and Thigh (M14).	Footrest surface to the clothed Dorsal Juncture of Calf and Thigh
EM30	Buttock-Knee Length	The horizontal distance between Buttock Point, Posterior and the Knee Point, Anterior (M25).	The horizontal distance between the clothed Buttock Point, Posterior and the clothed Knee Point, Anterior.
EM31	Buttock-Popliteal Length	The horizontal distance between Buttock Point, Posterior and the Dorsal Juncture of Calf and Thigh (M26).	The horizontal distance between clothed Buttock Point, Posterior and the clothed Dorsal Juncture of Calf and Thigh.
*	Elbow Rest Height	Sitting surface to Olecranon bottom (M11).	Sitting surface to the clothed Olecranon bottom.
*	Sitting Eye Height	Sitting surface to Ectocanthus (M09).	Sitting surface to clothed Ectocanthus.

** PECCFs for Elbow Height and Sitting Eye Height were not derived due to problems with the measurement techniques and so these measures have not been allocated an ID.*

Based on the original set of encumbered measures identified, the landmarks specified in Table 5 were not able to be visually identified and required a marker. The methods of transferring the landmarks to SCE One and SCE Two are specified in Table 5.

Table 5: Encumbered Anthropometric Landmarks

No.	Landmark	Semi-Nude Marker	Transfer to SCE 1	Transfer to SCE 2
1	Acromion (left and right)	Sticker & Prism	Take off prism, palpate through CPCU shirt and attach new prism	Take off prism, palpate through CPCU shirt and attach new prism
2	1st metatarsophanangeal protrusion (right)	Sticker & Prism	Take off prism, palpate through combat boot and attach new prism	Sticker stays in position – no action
3	5th metatarsophanangeal protrusion (right)	Sticker & Prism	Take off sticker, palpate through CPCU shirt and attach new sticker	Sticker stays in position – no action
4	Lateral Malleoulus (right)	Sticker	Take off sticker, palpate through CPCU shirt and attach new sticker	Sticker stays in position – no action

3. Data Collection

3.1 SCE Fitting

It was originally planned that the semi-nude measures from participants would be used to identify and allocate clothing and equipment based on the manufacturers' sizing guides. These were identified as follows:

- Operational Combat Uniform (OCU) pants (waist circumference and inside leg seam measurement);
- OCU shirt (chest circumference and height);
- Helmet (head circumference);
- Gloves (hand circumference, hand width and hand length); and
- TBAS (chest circumference).

It was also the intention for new uniforms and equipment to be obtained to eliminate any changes to size and fit caused by wear of clothing items. However, it was only possible to obtain two different sizes of uniform, one size of TBAS Tier 2, one size of TBAS Tier 3; all had been previously used. Helmets and new gloves were sourced in all available sizes. Due to the number of uniforms and TBAS available, a more pragmatic approach had to be adopted and was based on a 'best fit' allocation rather than manufactures' sizing guidelines.

3.2 SCE Dressing Protocol

When taking semi-nude anthropometric measures male subjects wore tight-fitting briefs and female subjects wore high-rise underpants and stretch midriff tops as per the ADF Anthropometric Survey (2012): Landmarking and Measurement Manual [10].

To reduce the potential for changes introduced by participants donning the SCE in different ways; the measurer oversaw each participant dressing themselves in the different ensembles and ensured a certain order of dress was adopted (Figure 3). Subjects commenced the protocol from the semi-nude condition.

Once a subject was in the required anthropometric posture prior to measurements, garments were smoothed out to eliminate biases leading to larger than actual measurements which can be caused by bunching of garments at joints and gathering of spare material.

1. Put on OCU shirt.

↓

2. Put on OCU pants (ensuring all pockets are empty and closed).

↓

3. Tuck OCU shirt into OCU pants.

↓

4. Insert elbow pads.

↓

5. Insert knee pads.

↓

6. Put on socks.

↓

7. Put on boots and tie up.

↓

8. Do up Velcro tabs at hem of OCU pants.

↓

9. Put on TBAS – do up cummerbund.

↓

10. Put on helmet and adjust to fit.

Figure 3: SCE Dressing Protocol

3.3 Dress/Redress Reliability Assessment

The way people don clothing and equipment can vary across repeated dressings and, as such, it is reasonable to assume that there are differences in the way clothing and equipment hangs and fits on each occasion. It was decided to explore such differences with the ADF SCE by taking the set of measures for each condition twice and so allowing for a within-subject comparison of the encumbered measures. Subjects were required to completely doff all clothing, down to the semi-nude condition, and then re-dress. All measures were taken from each subject on the same day so as not to introduce any bias caused by taking measures over different days.

3.4 Subject and Researcher Flow Path

A complete set of measures were taken from each subject during individual sessions where only the subject and two researchers were present. One researcher took all of the measurements and another researcher acted as scribe to record the measures and to assist in any measurements which required two measurers. The 3D scanner was calibrated every morning prior to measures being taken.

As the only difference between the ensembles of the DCC and the Vehicle Crew was the tier of TBAS and helmet worn; only those measures which would be affected by the change of equipment were taken for the Vehicle Crew condition. These measures were:

1. Stature
2. Weight
3. Chest Breadth
4. Chest Depth
5. Chest Circumference
6. Abdominal Extension
7. Waist Circumference
8. Forearm-Forearm
9. Bideltoid Breadth

The sequence of stages for both the subject and the researcher is presented in Figure 4. The order of conditions was semi-balanced to minimise the effect of postural fatigue on the measures, consequently, the flow path in Figure 4 only represents one order.

Subjects were briefed and provided informed consent as per the Survey Brief (Appendix D) and Australian Defence Human Research and Ethics Committee (ADHREC) Protocol 499/07: General Anthropometry: Generic Protocol (Appendix E).

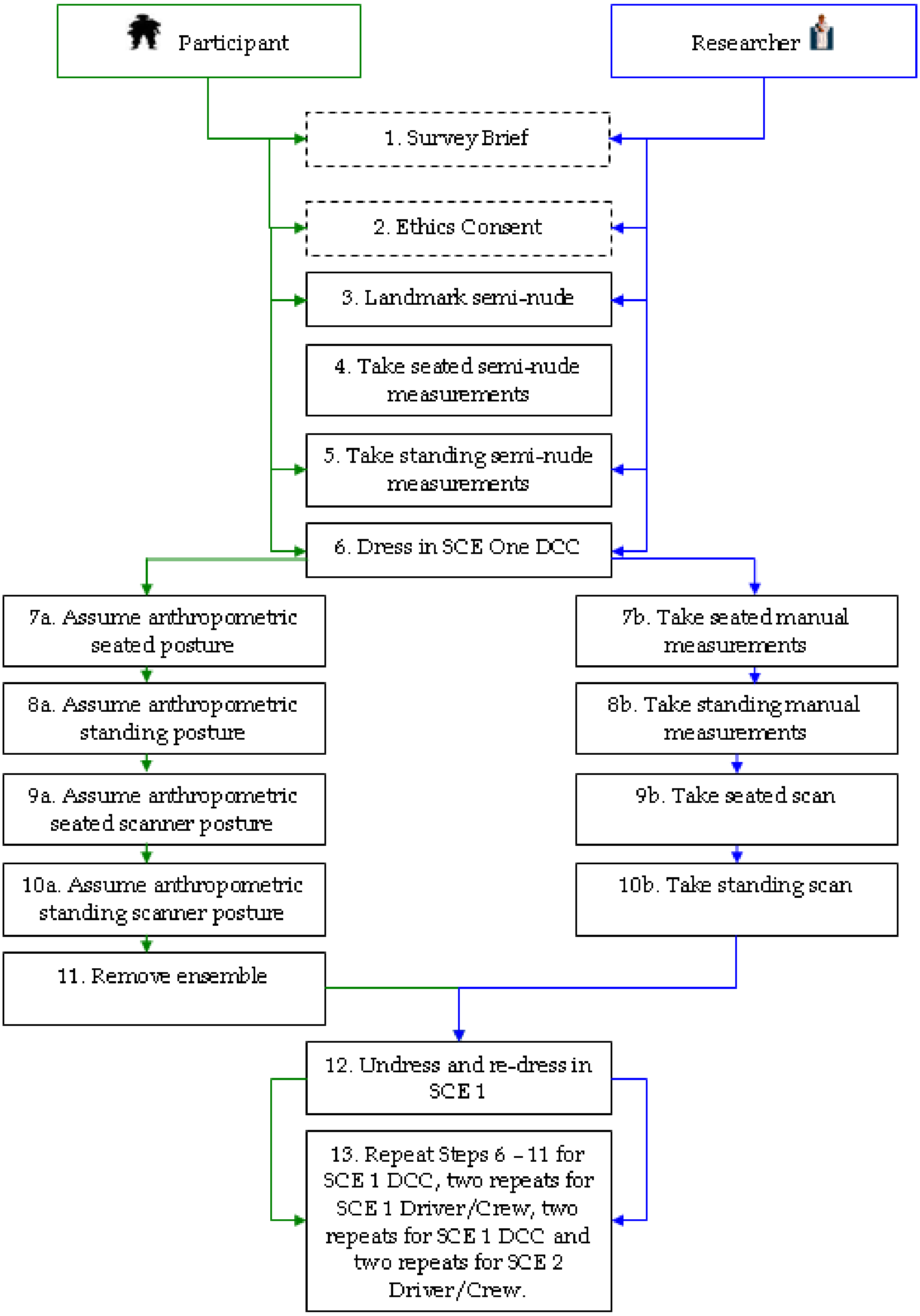

Figure 4: Subject and Researcher Flow Path

3.5 Measurement Extraction

3.5.1 Manual Measures

The manual measurements were recorded at the time the measure was taken. As with traditional anthropometric measurement methods, each measure was taken twice to reduce the potential for a measurement or recording error to be entered into the dataset. Where there was a difference of 2% between the two measures, a third measure was taken. The rationale for using 2% difference between the first two measures as a TEM threshold was because 1% was used in AWAS and an extra 1% was added as slightly more variation was expected with clothed measures and this was viewed as acceptable.

Due to the minimal number of subjects in the pilot survey only one measurer was used to landmark and take all semi-nude and encumbered measures from all subjects. The tester was International Society for the Advancement of Kinanthropometry (ISAK) Level 1 accredited. The amount of tension applied to the encumbered measures to compress the clothing was judged by the tester and, as the same person was taking all the measures, the potential for differences was minimised.

The semi-nude manual measures were taken in-line with the methods detailed in the ADF Anthropometric Survey (2012): Landmarking and Measurement Manual [10]. The encumbered manual measures were taken in-line with the encumbered anthropometric definitions provide in Appendix C.

An Excel spreadsheet had been set up to directly record all measures. For future surveys the Excel spreadsheet used to collect the measurements should be iterated to make the spreadsheet useful for collection of encumbered measures. This would include, but is not limited to, the immediate calculation of the relevant PECCF (encumbered measure minus semi-nude measure), identifying if the difference between the first and second PECCF is acceptable or if a third measure is required and a sanity check to determine if the PECCF is realistic. The development of the spreadsheet will require the identification of acceptable percentages of difference between the first and second measures. This will allow for real time exploration of any outliers and, hopefully, reduce the level of variance seen in the results of the pilot survey (Recommendation 1a).

3.5.2 3D Scan Measures

The measures taken in the Vitus XXL require processing in *ScanworX* Editor (*Human Solutions,* Kaiserslautern, Germany), conversion from an obj. file to a ply. format using *Plytool+* to allow manual extraction of the measures in CySlice.

The steps required to convert the file and obtain each scanned measure are provided in Appendix F. Information from the analysis conducted on the AWAS data was used to help develop the required steps for extracting the encumbered anthropometric data. Examples of the seated and standing 3D scanned images are shown in Figure 5 and Figure 6.

Figure 5: Seated Scan

Figure 6: Standing Scan

4. Analysis

4.1 Introduction

A number of considerations were addressed as part of the pilot survey to help refine the methodology for future surveys. Some of these considerations related to procedural decisions, and others to validity and reliability of the measures derived from the different measurement techniques. In order to assess these factors, a series of analyses were conducted:

- Intra-tester TEM for each measure;
- Coefficient of Variation (CV) and sample size;
- Percentage increase of encumbered measures to semi-nude measures; and
- Variation between first and re-dress condition.

4.2 TEM

There are a number of reasons why measurements, taken from the same location on an individual, by the same measurer, may be different. When considering encumbered measures, these reasons may include inconsistency in measuring technique, movement of landmarks, differences in amount of compression applied and postural change.

Intra-tester TEM is the SD of a measurement, taken twice, by one measurer and shows their error margin for that specific measure. As all of the measures in the pilot survey were taken by the same measurer, the measures with a lower TEM are deemed to be more reliable. The TEMs were only calculated for those measures which were taken manually.

Although some outliers were removed when deriving the final set of PECCFs, all data points were included in the calculation of the TEMs. Absolute TEM is calculated using the following equation [12]: absolute TEM = $\sqrt{\frac{\sum d^2 i}{2n}}$

Where:
Σd^2 = summation of deviations raised to the second power,
n = number of volunteers measured,
i = the number of deviations.

As there are gross differences between some of the measures, for example stature can be >1990 mm whereas hand thickness can be <33 mm, it is beneficial to convert the absolute TEM (mm) to a relative TEM (%) which allows for standardisation so measures can be compared. The relative TEM expresses the error as a percentage corresponding to the total average of the measure to be analysed.

The relative TEM is calculated using the following equation: relative TEM = $\frac{TEM}{VAV} x 100$

Where:
TEM = Technical Error of Measurement
VAV = Variable average value

To obtain the VAV the mean of the 1st and 2nd measurements was calculated, the means from all participants for each measure, were summed and divided by the number of participants. Essentially the VAV is the average of all the participant averages for a specific measurement.

4.3 Sample Size

When determining the required sample size for surveys, the use of similar data from a similar population is beneficial. Therefore, the data gathered as part of the pilot survey can be used to determine the sample sizes required for future surveys. As the calculation for deriving sample sizes used the (CV), which takes into account both the Standard Deviation (SD) and the mean of each measure, it is also a useful tool to examine differences between the measures from each condition. Only the sample size for those measures which were taken manually were calculated.

The equation provided in ISO 15535:2006(E) [14] was used to calculate the 95% confidence, 1% relative accuracy (precision):

$$N = \left(1.96x\frac{cv}{1}\right)^2 x(1.534)^2$$

The average measure for each participant was used to calculate the CV of each measure using the following equation [14]:

$$C\upsilon = \frac{\sigma}{\mu} \text{ x } 100$$

Where:
σ = standard deviation
μ = mean

Helmet circumference, helmet breadth and helmet length were removed from the sample size calculations as the raw measures are based on the helmet size and so the CV and subsequent sample size calculations are based on the difference between two helmet sizes. Weight was also removed as a standard weight was applied to each participant to represent the mass of clothing and equipment.

4.4 Percentage Increase from Semi-Nude to Encumbered

To appreciate the measures which were subject to the largest increases when participants were clothed and wearing equipment, the percentage increase from semi-nude to the related encumbered measure were derived using the following calculation:

$$\left(\frac{|\ encumbered\_measure - semi\_nude\_measure\ |}{|\ semi\_nude\_measure\ |} \right) x100$$

For example, when considering semi-nude Stature (180.7 mm) and DCC (SCE One) Stature (187.3 mm) the calculation would be:

$$\left(\frac{187.3 - 180.7}{180.7} \right) x100 = 3.65\% \text{ increase}$$

Although some measures, such as Foot Length, were only measured in one condition and others, such as Helmet Circumference, are only measured in two – the four conditions have been populated with all applicable measures to allow for comparison across the conditions. For example, all foot measures have been included in all four conditions.

4.5 Re-dress Variation

During the survey participants had one full set of measures taken in each condition. They were then asked to un-dress and re-dress in the same condition, and another full set of measures were taken. Analysis of the initial and re-dress condition allows for within-subject comparison.

To analyse the data, the PECCFs for all measures in each initial and re-dress condition were derived.

If a higher number of participants had been sampled then it would have been useful to conduct a Bland-Altman Analysis which includes random and systematic error along with supplying 95% confidence intervals when comparing the agreement between two difference datasets. It is recommended that this is performed in future surveys (Recommendation 1c).

5. Results

5.1 TEM

TEMs should be commensurate with the magnitude of the differences they are measuring [13] and so the absolute and relative TEMs for each measure were examined and are presented in Table 6. The TEMs for the semi-nude measures provide an indication of the reliability of the measurer and so differences between the encumbered and semi-nude TEMs for each measure should indicate errors or variations caused by either the wearing of clothing/equipment or the measuring techniques used for the encumbered measures.

Due the potential for variance in the encumbered measures, higher TEMs for SCE One measures versus semi-nude and, again, higher TEMs for SCE Two measures versus SCE One were expected. However, the results show that, overall, the TEM for semi-nude and encumbered measures were low. Note that the TEMs were conducted on all measures which were taken, including the outliers to fully explore the method. The outliers were removed when the PECCFs were derived.

Table 6: Absolute and Relative TEMs.

Measure		Semi-Nude		DCC (SCE One)		Vehicle Crew (SCE One)		DCC (SCE Two)		Vehicle Crew (SCE Two)	
		Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)
EM01	Stature	1.16	0.07	1.50	0.08	1.12	0.06	1.05	0.05	0.45	0.02
EM02	Weight	-	-	-	-	-	-	-	-	-	-
EM03	Helmet Circumference	-	-	-	-	-	-	-	-	-	-
EM04	Helmet Breadth	-	-	-	-	-	-	-	-	-	-
EM05	Helmet Length	-	-	-	-	-	-	-	-	-	-
EM06	Acromion Height	3.77	0.27	-	-	-	-	1.52	0.10	-	-
EM07	Chest Circumference	3.55	0.37	2.17	0.16	3.25	0.29	2.68	0.19	2.28	0.19
EM08	Chest Breadth	2.55	0.92	1.45	0.48	2.11	0.71	3.49	1.08	2.53	0.80
EM09	Chest Depth	1.10	0.50	1.52	0.37	0.67	0.24	2.41	0.58	1.34	0.45
EM10	Waist Circumference (Omphalion)	2.66	0.31	3.97	0.26	1.55	0.16	2.41	0.16	1.61	0.16
EM11	Buttock Circumference	2.38	0.23	2.60	0.24	-	-	3.39	0.30	-	-
EM12	Crotch Height	3.77	0.48	1.32	0.17	-	-	0.32	0.04	-	-
EM13	Hand Circumference	0.55	0.27	0.59	0.25	-	-	1.30	0.56	-	-
EM14	Hand Breadth	0.63	0.76	0.39	0.42	-	-	0.32	0.33	-	-
EM15	Hand Length	0.45	0.24	0.50	0.25	-	-	0.95	0.47	-	-
EM16	Hand Thickness	0.50	1.73	0.39	1.13	-	-	0.45	1.34	-	-
EM17	Ankle Height	-	-	-	-	-	-	-	-	-	-
EM18	Foot Breadth, Horizontal	0.50	0.60	0.45	0.49	-	-	-	-	-	-
EM19	Foot Length	0.80	0.34	0.39	0.14	-	-	-	-	-	-
EM20	Ball of Foot Length	0.46	0.28	0.45	0.24	-	-	-	-	-	-
EM21	Sitting Height	0.92	0.10	6.53	0.70	1.22	0.13	1.48	0.15	1.34	0.14

Measure		Semi-Nude		DCC (SCE One)		Vehicle Crew (SCE One)		DCC (SCE Two)		Vehicle Crew (SCE Two)	
		Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)
EM22	Acromion Height, Sitting	1.20	0.21	-	-	-	-	0.95	0.16	-	-
EM23	Bideltoid Breadth	2.97	0.65	1.28	0.24	1.34	0.26	1.92	0.33	1.14	0.21
EM24	Forearm-Forearm Breadth	1.29	0.28	3.76	0.59	2.22	0.38	1.48	0.21	1.45	0.22
EM25	Abdominal Extension Depth, Sitting	1.26	0.59	1.20	0.28	0.81	0.27	1.34	0.30	1.84	0.61
EM26	Hip Breadth, Sitting	0.63	0.17	1.95	0.48	-	-	1.97	0.48	-	-
EM27	Thigh Clearance	0.74	0.48	1.00	0.59	-	-	1.64	0.89	-	-
EM28	Knee Height, Sitting	0.67	0.13	1.63	0.27	-	-	0.55	0.09	-	-
EM29	Popliteal Height	2.01	0.49	1.02	0.22	-	-	1.90	0.41	-	-
EM30	Buttock-knee Length	2.25	0.38	0.89	0.15	-	-	1.38	0.21	-	-
EM31	Buttock-Popliteal Length	3.45	0.74	2.26	0.49	-	-	2.57	0.53	-	-

Semi-Nude
No semi-nude absolute TEM was over 4 mm and no semi-nude relative TEM was over 2%.

SCE One
DCC sitting height shows a high absolute TEM of 6.53 mm (although only 0.70% relative TEM). The semi-nude sitting height absolute TEM was only 0.92 mm and so reasons for this increase need to be considered. One risk of taking manual measurements when participants are encumbered is that they will be subject to postural fatigue and so the participants may have altered their posture in between first and second measures, hence the variation. However, the absolute TEM for all other encumbered conditions sitting heights are <1.5 mm and so is less likely to be due to postural fatigue. Measurements from Participant One and Participant Two showed differences of 6 mm and 28 mm respectively. When these measurements are removed from the calculation the TEM becomes 1.41 mm and so the high TEM is likely to be due to tester or recorder error for those subjects rather than a systematic error caused by the encumbered measures or the measuring technique.

Although postural fatigue may not have influenced the variation in sitting height TEM, the raw data shows a number of encumbered measures which produced a negative difference when compared to their corresponding semi-nude measure. It is recommended that further work be conducted to examine postural changes caused by the wearing of combat clothing and equipment (Recommendation 2a).

There was an increase in absolute TEM from 1.29 mm (semi-nude) to 3.76 mm (DCC SCE One) for Forearm-Forearm Breadth. Vehicle Crew (SCE One), and both SCE Two conditions (2.22 mm, 1.48 mm and 1.45 mm) were not notably different. The measurement from Participant One showed a difference of 14 mm between initial and second measurement. When this is removed from the TEM calculation the result is an absolute TEM of 2.20 mm. Again, this shows that it is likely to be a measurer or recorder error for one of the measures for Participant One rather than a systematic error or problem with the measurement of Forearm-Forearm Breadth.

All other DCC (SCE One) and Vehicle Crew (SCE One) measure absolute TEMs were <4 mm and relative TEMs were <1.5%.

SCE Two
All DCC (SCE Two) and Vehicle Crew (SCE Two) measure absolute TEMs were <3.5 mm and relative TEMs were <1.5%. The small TEMs with minimal deviation when semi-nude measures are compared to encumbered measures indicate that the methods used for manual measurements appeared reliable. Due to this being a pilot survey with few subjects, only one measurer was used to negate between-measurer variability. In future surveys it would be beneficial to explore between-measurer variability on encumbered measures (Recommendation 2b).

5.2 Sample Size

The sample size calculations for 1% precision & 95% confidence for all conditions are presented in Table G-1 in Appendix G, along with the sample size calculations for the AWAS (full survey). The results of the sample size calculations show large differences between the numbers of participants required in future surveys. There are also differences between the number of participants calculated for AWAS (using calculations from $n = 2170$) and the number of participants calculated using the semi-nude data from the pilot survey with a maximum n of 10. This indicates the problem of basing calculations on a small sample size. For both SCE Two conditions a maximum of six participants were measured, and for a number of measures it was only possible to measure three participants. Due to this low number the sample sizes for SCE Two conditions are not considered further.

It was expected that the encumbered measures would require greater sample sizes than semi-nude measures due to the variation between subjects wearing clothing and equipment. However, this was not the case. Discounting SCE Two conditions, all bar five of the largest sample size requirements were from semi-nude measures and of these five, the sample sizes were very similar to the semi-nude requirement(s). This is likely due to some measurements being influenced by equipment of a fixed size and the rigidity of the items which is likely to reduce the variance in equipment compression. For example, chest circumference is one of the most variable measures, yet the low sample size predictions for SCE One indicate a low level of variability. Although the body armour was able to be adjusted, only one size of body armour was used. The low variability can be explained and highlights the importance of future surveys ensuring the full range of clothing and equipment sizes are available (Recommendation 1b). It is also of note that the semi-nude Waist Circumferences had a very low SD as all ten participants had very similar Waist Circumferences which is a further problem with the low sample number. This is also supported by the comparatively low sample size prediction for Forearm-Forearm Breadth, 741 for semi-nude and 182 for DCC (SCE One). Whereas, when taking the measure in the semi-nude condition, the arms generally do not touch the body; the participants likely rested the inside of their arms against the body armour, which being of a fixed size, produced less variability in the results.

Lower precision and confidence could be considered when determining sample sizes for future surveys and sample size calculations for 1% precision & 95% confidence, 2% precision & 95% confidence, 1% precision & 90% confidence and 2% precision & 90% confidence are presented in Appendix G.

5.3 Percentage Increase from Semi-Nude to Encumbered

The percentage increase was calculated for all measures in each of the four conditions and is presented in Table 7. The percentage difference was calculated from the mean semi-nude measurement, e.g. stature, of all participants and the mean encumbered measurement of all participants.

As would be expected for the DCC (SCE One) and DCC (SCE Two) conditions, the measures which encompass the TBAS and pouches feature the largest percentage increase with Abdominal Extension Depth showing the greatest augmentation with 124% and 123% increase respectively, second being Chest Depth with an 111% and 110% increase respectively and thirdly, Waist Circumference (Omphalion) at 77% and 78% increase respectively.

The measures which demonstrated the largest augmentation for the Vehicle Crew (SCE One) and Vehicle Crew (SCE Two) conditions were the head and foot measures, closely followed by Waist Circumference (Omphalion), and Abdominal Extension Depth, Sitting.

Table 7: Percentage Increase from Semi-Nude to Encumbered Condition

DCC (SCE One)			Vehicle Crew (SCE One)			DCC (SCE Two)			Vehicle Crew (SCE Two)		
Measure		**% Inc.**	**Measure**		**% Inc.**	**Measure**		**% Inc.**	**Measure**		**% Inc.**
EM25	Abdominal Extension Depth, Sitting	124	EM04	Head Breadth	77	EM25	Abdominal Extension Depth, Sitting	123	EM04	Head Breadth	77
EM09	Chest Depth	111	EM19	Foot Length	70	EM09	Chest Depth	110	EM19	Foot Length	70
EM10	Waist Circumference	77	EM17	Ankle Height	63	EM10	Waist Circumference	78	EM17	Ankle Height	63
EM19	Foot Length	70	EM20	Ball of Foot Length	60	EM19	Foot Length	70	EM20	Ball of Foot Length	60
EM17	Ankle Height	63	EM03	Head Circumference	57	EM17	Ankle Height	63	EM03	Head Circumference	57
EM20	Ball of Foot Length	60	EM05	Head Length	44	EM20	Ball of Foot Length	60	EM10	Waist Circumference	46
EM04	Head Breadth	51	EM10	Waist Circumference	43	EM04	Head Breadth	50	EM05	Head Length	44
EM07	Chest Circumference	47	EM25	Abdominal Extension Depth, Sitting	41	EM07	Chest Circumference	47	EM25	Abdominal Extension Depth, Sitting	43
EM03	Head Circumference	41	EM09	Chest Depth	28	EM24	Forearm-Forearm Breadth	47	EM24	Forearm-Forearm Breadth	41
EM05	Head Length	38	EM24	Forearm-Forearm Breadth	26	EM03	Head Circumference	41	EM09	Chest Depth	36
EM24	Forearm-Forearm Breadth	37	EM07	Chest Circumference	18	EM05	Head Length	38	EM07	Chest Circumference	23
EM16	Hand Thickness	17	EM16	Hand Thickness	17	EM23	Bideltoid Breadth	27	EM23	Bideltoid Breadth	22
EM23	Bideltoid Breadth	16	EM13	Hand Circumference	15	EM27	Thigh Clearance	18	EM27	Thigh Clearance	18
EM13	Hand Circumference	15	EM28	Knee Height, Sitting	14	EM28	Knee Height, Sitting	18	EM28	Knee Height, Sitting	18
EM28	Knee Height, Sitting	14	EM23	Bideltoid Breadth	13	EM08	Chest Breadth	16	EM08	Chest Breadth	14
EM29	Popliteal Height	12	EM29	Popliteal Height	12	EM16	Hand Thickness	14	EM16	Hand Thickness	14
EM18	Foot Breadth, Horizontal	11	EM18	Foot Breadth, Horizontal	11	EM13	Hand Circumference	13	EM13	Hand Circumference	13
EM27	Thigh Clearance	10	EM27	Thigh Clearance	10	EM29	Popliteal Height	12	EM29	Popliteal Height	12

DCC (SCE One)			Vehicle Crew (SCE One)			DCC (SCE Two)			Vehicle Crew (SCE Two)		
Measure		% Inc.	Measure		% Inc.	Measure		% Inc.	Measure		% Inc.
EM08	Chest Breadth	9	EM01	Stature	8	EM14	Hand Breadth	11	EM14	Hand Breadth	11
EM14	Hand Breadth	9	EM14	Hand Breadth	8	EM18	Foot Breadth, Horizontal	11	EM18	Foot Breadth, Horizontal	11
EM26	Hip Breadth, Sitting	8	EM26	Hip Breadth, Sitting	8	EM11	Buttock Circumference	11	EM11	Buttock Circumference	11
EM15	Hand Length	6	EM08	Chest Breadth	7	EM26	Hip Breadth, Sitting	10	EM26	Hip Breadth, Sitting	10
EM11	Buttock Circumference	6	EM15	Hand Length	6	EM30	Buttock-Knee Length	9	EM01	Stature	9
EM06	Acromion Height	5	EM11	Buttock Circumference	6	EM01	Stature	8	EM30	Buttock-Knee Length	9
EM01	Stature	4	EM06	Acromion Height	5	EM21	Sitting Height	8	EM21	Sitting Height	9
EM21	Sitting Height	3	EM21	Sitting Height	4	EM06	Acromion Height	6	EM06	Acromion Height	6
EM22	Acromion Height, Sitting	3	EM22	Acromion Height, Sitting	3	EM15	Hand Length	5	EM15	Hand Length	5
EM30	Buttock-Knee Length	2	EM30	Buttock-Knee Length	2	EM22	Acromion Height, Sitting	4	EM22	Acromion Height, Sitting	4
EM31	Buttock-Popliteal Length	-1	EM31	Buttock-Popliteal Length	-1	EM31	Buttock-Popliteal Length	1	EM31	Buttock-Popliteal Length	1
EM12	Crotch Height	-3	EM12	Crotch Height	-3	EM12	Crotch Height	-6	EM12	Crotch Height	-6

5.4 Re-dress Variation

The difference between the initial and re-dress PECCFs were calculated in terms of millimetres and percentage and are presented in Appendix H. Where the percentage difference was deemed to be high (over 20%) the data from each participant was reviewed and an explanation sought as to the reason for the difference. It was then decided whether the variation was acceptable or whether modifications to the methodology/measurement technique should be considered for future surveys.

5.4.1 Male Acromion Height (EM06)

Male Acromion Height varied by 25% (11 mm) in the DCC (SCE Two) condition. No other Acromion Height re-dress values varied by >20%. The variation for SCE One, for males and females was >15% difference with males showing a 7 mm variation and females a 4 mm variation. The reason for the increased variation when wearing SCE Two is likely due to the increased bulk of the CW jacket and the potential for variation in the compression applied by the measurer. It is recommended that consideration be given to modifying the measuring equipment to help increase the accuracy of this measure, for example, weighting the anthropometer to apply a consistent level of pressure to compress the clothing may be a solution, (Recommendation 1f).

5.4.2 Chest Breadth (EM08)

Female Chest Breadth varied by 28% (5 mm) between the initial and the re-dress condition in the Vehicle Crew (SCE One) condition. Male Chest Breadth also varied in the DCC (SCE Two) condition. The variation in this condition was 28% with an actual difference of 7 mm. No other Chest Breadth re-dress values varied by >20%. The difference was likely due to the location of the under-arm seam of the Crye combat shirt. Chest Breadth was taken at the maximum horizontal breadth at the height of the compressed under-arm seam.

5.4.3 Crotch Height (EM12)

Female Crotch Height varied by 20% (4mm) in the DCC (SCE One) condition. No other Crotch Height re-dress values varied by >20%.

The definition of the encumbered measure is 'Standing surface to crotch seam of pants' and the participant pulls the anthropometer into position which alone introduces a potential for error. The relative TEM for semi-nude Crotch Height was 3.77 mm with DCC (SCE One) and DCC (SCE Two) Crotch heights being notable less at 1.32 mm and 0.32 mm respectively. Due to the nature of how the measurement is taken and the TEM, the difference between the initial and redress conditions is to be expected and is deemed acceptable.

5.4.4 Hand Breadth (EM14)

Female Hand Breadth varied by 20% (1 mm) in the DCC (SCE One) condition. This is the only Hand Breadth measure that showed a difference of 20% and as the actual difference is 1 mm this is viewed as acceptable.

5.4.5 Hand Length (EM15)

Female Hand Length varied by 22% (2 mm) in the DCC (SCE One) condition. Male Hand Length in the DCC (SCE Two) condition varied by 33% but again was an actual difference of 2 mm. No other Hand Length re-dress values varied by >20%. Although the percentage difference between the initial and re-dress conditions is high, as the actual difference for both measure was 2 mm this is viewed as acceptable.

5.4.6 Hand Thickness (EM16)

Male Hand Thickness for the DCC (SCE One) condition varied by 25% between the initial and re-dress condition. The Male Hand Thickness for the DCC (SCE Two) condition varied by 67%. No other Hand Thickness re-dress values varied by >20%. As with the Hand Length variation, the actual difference was only 1 mm in the DCC (SCE One) condition and only 2 mm in the DCC (SCE Two) condition and is viewed as acceptable.

5.4.7 Ball of Foot Length (EM20)

Male Ball of Foot Length for the DCC (SCE One) condition varied by 33% between the initial and the re-dress condition. No other Ball of Foot Length re-dress values varied by >20%. The actual difference between the initial and re-dress condition for Male Ball of Foot Length was 3 mm and the variation is viewed as acceptable.

5.4.8 Sitting Height (EM21)

Male Sitting Height varied by 39% (13 mm) in the Vehicle Crew (SCE One) condition. No other Sitting Height measures varied by >20%. As discussed in the TEM analysis in Sub-section 5.1, a risk of taking manual measurements when participants are encumbered, and also for a long duration of time, is that they may be subject to postural fatigue. The participant's posture and subsequently their measurements may vary. It is recommended that further work be conducted to examine postural changes caused by the wearing of combat clothing and equipment (Recommendation 2a).

5.4.9 Hip Breadth, Sitting (EM26)

Within the DCC (SCE One) condition, both Male and Female Hip Breadth, Sitting measures varied >20% between the initial and re-dress conditions, 33% and 30% respectively. The actual differences were 5 mm for the male measures and 8 mm for the female measures. No other Hip Breadth, Sitting re-dress values varied by >20%.

The PECCF for Male Hip Breadth, sitting was derived from the measurements taken from four participants in both the initial and re-dress condition (SCE One). The measures for Participants Two, Three and Four are very similar between the initial and re-dress condition. The largest difference is between Participant Five's measures, 5 mm in the initial condition and 23.5mm in the re-dress (Table 8). It is assumed that the re-dress value is due to measurement error and if Participant Five's measures are removed then the initial PECCF becomes 19 mm and the re-dress PECCF becomes 19 mm.

Table 8: Male Hip Breadth, Sitting Re-Dress Variation (EM26)

Participant	Initial Measure – SCE One (mm)	Re-dress Measure – SCE One (mm)	Difference (mm)
Two	5	5.5	0.5
Three	29	29	0
Four	21.5	22	0.5
Five	5	23.5	18.5

As the only real difference is between the initial and re-dress of one participant the variation could be due to measurer or recorder error for that one participant. However, female Hip Breadth, Sitting also showed a variation of 30% (8 mm) between initial and redress conditions. The largest difference between the initial and re-dress for one participant in the female dataset was 14 mm and the smallest was 0.5 mm. As the TEM for Hip Breadth, Sitting was 1.95 mm, it is likely that the encumbered Hip Breadth, Sitting measure was affected by how a user wears their clothing. In addition to the assumption that users may don their clothes/equipment on differently each time, we could also assume that participants sit/stand slightly differently each time they are measured. Postural variation was minimised through the use of specific anthropometric postures, the anthropometric box, foot plates and taking all measurements at the same time.

5.4.10 Popliteal Height (EM29)

Male Popliteal Height in the DCC (SCE One) condition varied by 27% and had a variation of 9 mm when comparing the PECCF for the initial and re-dress conditions. No other Popliteal Height varied greater than 20%. As with Thigh Clearance it is likely that the bunching of material behind the knee will be different between the initial and re-dress condition and so cause differences in the measures.

5.4.11 Buttock-Popliteal Length (EM31)

Within the DCC (SCE One) condition, male Buttock-Popliteal Length varied by 22% and female varied by 62%. The male DCC (SCE Two) measure varied by 25%.

As with Male Popliteal Height, the difference between the initial and re-dress condition was likely due to the change in the bunching of material behind the knee. Whilst the Male Buttock-Popliteal Length actual variation was acceptable (1 mm in SCE One and 2 mm in SCE Two), the female actual variation was 8 mm which is attributed to postural change.

5.5 Addition of Equipment Measures to Provide PECCFs

The procurement of military clothing and equipment frequently changes in order to support the specific requirements of current operations and mission profiles. It is, therefore, important to develop a methodology which allows for the PECCF dataset to be frequently updated and remain current. One way of achieving this would be to repeatedly run a small scale survey where participants have the relevant encumbered measurements taken. Consideration was also given to a different method of up-dating the dataset. This was to take measurements from the items of equipment related to a certain measure and then add these equipment measures, which essentially would be the PECCF, to the semi-nude measurements. For example, the increase in encumbered chest breadth, when compared to semi-nude chest breadth, is the addition of Crye shirt, TBAS (with plates) and the pouch/item of equipment which is most lateral on the front and rear of TBAS. Therefore, for DCC (SCE One), the widths of the following equipment and the sum of the width measurements would represent the PECCF for chest depth:

- Top, rear of TBAS (with plates);
- Top, front of TBAS (with plates);
- Camelbak (top);
- Grenade and pouch;
- Crye Shirt (front material); and
- Crye Shirt (front material).

To establish if the addition of equipment measures would be a viable methodology, the equipment measures required for each anthropometric measurement were taken and compared with the PECCFs derived from the survey for that measurement. The results, presented in Table 11, show that for Chest Depth, Hand Thickness, Hand Breadth, Ankle Height, Abdominal Extension Depth (sitting), Hip Breadth and Thigh Clearance the results produced by measuring the clothing and equipment are similar to the PECCF and, in theory, this method could be used to up-date these measures. However it is not possible to use the method to identify the PECCF for the following measures:

1. Stature
2. Helmet Circumference
3. Helmet Breadth
4. Helmet Length
5. Chest Circumference
6. Waist Circumference (Omphalion)
7. Buttock Circumference
8. Crotch Height
9. Hand Circumference
10. Foot Length
11. Foot Breadth, Horizontal
12. Ball of Foot Length
13. Sitting Height
14. Knee Height
15. Popliteal Height

There were also a number of measures which, although it was possible to use the method, did not produce results similar to the derived PECCFs:

1. Acromion Height
2. Chest Breadth
3. Hand Length
4. Acromion Height, Sitting
5. Bideltoid Breadth
6. Forearm-Forearm Breadth
7. Buttock-Knee Length
8. Buttock-Popliteal Length

5.6 PECCF Evaluation

A number of lessons were learnt during the conduct and analysis of the data about each measure, within each condition. The conclusions drawn relate to whether the measurement definition and method are accurate and reliable, and subsequently whether it is acceptable to use the same definitions and technique in future surveys or whether modifications are required. Table 9 provides a list of all measures, the measurement method, rational for and problems with the definitions/techniques and recommendations for future surveys. Where different conditions use the same measurement method, and other no problems were experienced, the information is not repeated.

Table 9: PECCF Evaluation

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
DCC (SCE One)				
EM01	Stature	Manual (stadiometer)	The stadiometer was portable and, when wearing clothing and equipment, it was not possible for the participant to place their heels against the base and stand straight. This meant that the participants (and stadiometer) was prone to sway and was not sturdy enough to support the encumbered participant.	As the 3D body scanner is prone to occlusion at the top of the head/helmet it is not viable to take stature from a scan and so it is recommended that a more secure, sturdy stadiometer is used and consideration given to moving the base of the stadiometer forward to allow the participant to stand straight (the excess mass on the back of the participant does not allow for standing straight), (Recommendation 1d.
EM02	Weight	Separate calculation of combined mass of clothing and equipment worn	The method of separately calculating all of the clothing and equipment worn was adopted due to not being able to obtain all of the required equipment. Should all of the required equipment be obtained and donned on the participants then using scales would be sufficient.	Same method or use of scales if all clothing and equipment is available and worn.

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM03	Head Circumference	Calculation of πd where 'd' is the Helmet Breadth (EM04) or Length, (EM05) whichever is larger	The calculation of πd was used as the head circumference is obtained to represent the space claim of the encumbered head.	Same as per pilot survey (calculation).
EM04	Head Breadth	3D Scan	Using the 3D scan allowed for more accurate identification of the most lateral points on the helmet as there is a function built into the extraction software to identify these points.	Same as per pilot survey (3D Scan).
EM05	Head Length	3D Scan	Using the 3D scan allowed for more accurate identification of the most anterior/posterior points on the helmet then could be achieved through site and the use of callipers as there is a function built into the extraction software to identify these points and automatically calculating that point-to-point distance.	Same as per pilot survey (3D Scan).
EM06	Acromion Height	3D Scan	There were no problems identifying the acromion markers and using the 3D scan allowed for and accurate point-to-point distance to be calculated.	Same as per pilot survey (3D Scan).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM07	Chest Circumference	Manual (Girth Tape [2 person])	Chest Circumference was measured manually to ensure that the girth tape was placed (by two measurers) around the most lateral, posterior and anterior protruding edges of the pouches which were attached to TBAS. Although the method resulted in the girth tape not always being straight, it was observed that this method, which would result in a slightly larger circumference measurement, is preferred over using fixed landmarks and a straight girth tape which may likely result in an under-estimated circumference. As the end result is consideration of space claim, the method used in the pilot survey is the preferred option.	Same as per pilot survey (manual) but further testing could show that 3D scans would be as accurate for this measure (Recommendation 2c).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM08	Chest Breadth	Manual (Anthropometer)	Chest Depth was taken manually as some compression was required. Variability in the difference between each participant's semi-nude and encumbered measures were identified. It is thought that this is due to the definition, and subsequent measuring technique, where the Chest Breadth is measured at the point of the under-arm seam.	Same as per pilot survey (manual) but further testing could show that 3D scans would be as accurate for this measure (Recommendation 2c).
EM09	Chest Depth	Manual (Anthropometer)	Chest Breadth was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual) but further testing could show that 3D scans would be as accurate for this measure (Recommendation 2c).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM10	Waist Circumference	Manual (Girth Tape)	Waist Circumference was measured manually to ensure that the girth tape was placed (by two measurers) around the most lateral, posterior and anterior protruding edges of the pouches which were attached to TBAS. Although the method resulted in the girth tape not always being straight, it was observed that this method, which would result in a slightly larger circumference measurement, is preferred over using fixed landmarks and a straight girth tape which may likely result in an under-estimated circumference. As the end result is consideration of space claim, the method used in the pilot survey is the preferred option.	Same as per pilot survey (manual) but further testing could show that 3D scans would be as accurate for this measure (Recommendation 2c).
EM11	Buttock Circumference	Manual (Girth Tape)	Buttock Circumference was measured manually as compression of the combat pants and CWC pants was required. There were no problems identified with this method.	Same as per pilot survey (manual).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM12	Crotch Height	Manual (Anthropometer)	It is not possible to measure Crotch Height in the 3D scanner as it would require the participant's legs to be apart which would affect height. No problems were identified with taking Crotch Height manually.	Same as per pilot survey (manual).
EM13	Hand Circumference	Manual (Girth Tape)	Lack of definition in 3D scans means that Hand Circumference should be taken manually. No problems were identified with this method.	Same as per pilot survey (manual).
EM14	Hand Breadth	Manual (Bone Breadth Calipers)	Lack of definition in 3D scans means that Hand Breadth should be taken manually. No problems were identified with this method.	Same as per pilot survey (manual).
EM15	Hand Length	Manual – (Bone Breadth Calipers)	Lack of definition in 3D scans means that Hand Length should be taken manually. No problems were identified with this method.	Same as per pilot survey (manual).
EM16	Hand Thickness	Manual – (Bone Breadth Calipers)	Lack of definition in 3D scans means that Hand Thickness should be taken manually. No problems were identified with this method.	Same as per pilot survey (manual).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM17	Ankle Height	3D Scan	Ankle Height was identified and landmarked with a sticker, the measurement was then extracted from the 3D scan. The sticker did not show up clearly on all scans and so it was not possible to extract all measures.	The method of extracting the Ankle Height can be used in future if a landmark sticker with a better contrast to the boot is used to ensure that all Ankle Height measures are able to be extracted (Recommendation 1e).
EM18	Foot Breadth, Horizontal	Manual (Anthropometer)	Lack of definition in 3D scans means that Foot Breadth, Horizontal should be taken manually. No problems were identified with this method.	Same as per pilot survey (manual).
EM19	Foot Length	Manual (Anthropometer)	Lack of definition in 3D scans means that Foot Length should be taken manually. No problems were identified with this method.	Same as per pilot survey (manual).
EM20	Ball of Foot Length	Manual (Anthropometer)	Lack of definition in 3D scans means that Ball of Foot Length should be taken manually. No problems were identified with this method.	Same as per pilot survey (manual).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM21	Sitting Height	Manual (Anthropometer)	Lack of definition in 3D scans means that Sitting Height should be taken manually. A standard anthropometric box was used but due to the additional volume taken up by the encumbered participant it was sometimes difficult for the base of the anthropometer to be fully rested on the box which meant that the anthropometer wasn't as stable as it should have been. Additionally, as the anthropometer sat further away from the participant the measuring arms sometimes struggled to reach the desired landmark.	Same as per pilot survey (manual) but it is recommended that an anthropometric box with a larger surface area and an anthropometer with longer measuring arms be developed (Recommendation 1f).
EM22	Acromion Height, Sitting	3D Scan	There were no problems identifying the acromion markers and using the 3D scan allowed for and accurate point-to-point distance to be calculated.	Same as per pilot survey (3D Scan).
EM23	Bideltoid Breadth	Manual (Anthropometer)	Bideltoid Breadth was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual) but further testing could show that 3D scans would be as accurate for this measure (Recommendation 2c).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM24	Forearm-Forearm Breadth	Manual (Anthropometer)	As compression was required, this measure was taken manually. When taking encumbered measures, due to the wearing of body armour and pouches, the anthropometer sat further away from the participant and the measuring arms sometimes struggled to reach the desired landmark.	Same as per pilot survey (manual) but it is recommended that an anthropometer with longer measuring arms be developed (Recommendation 1f).
EM25	Abdominal Extension Depth, Sitting	Manual (Anthropometer)	Abdominal Extension Depth, Sitting was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual) but further testing could show that 3D scans would be as accurate for this measure (Recommendation 2c).
EM26	Hip Breadth	Manual (Anthropometer)	Buttock-Popliteal Length was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual).
EM27	Thigh Clearance	Manual (Anthropometer)	Buttock-Popliteal Length was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual).
EM28	Knee Height, Sitting	Manual (Anthropometer)	Buttock-Popliteal Length was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM29	Popliteal Height	Manual (Anthropometer)	Buttock-Popliteal Length was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual).
EM30	Buttock-Knee Length	Manual (Anthropometer)	Buttock-Popliteal Length was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual).
EM31	Buttock-Popliteal Length	Manual (Anthropometer)	Buttock-Popliteal Length was taken manually as some compression was required. There were no problems identified with this method.	Same as per pilot survey (manual).
-	Elbow Rest Height	3D Scan	Elbow Rest Height was extracted from a 3D scan as the measure did not require compression. However, it was not possible to place a perpendicular line from the Olecranon, Bottom, to the top of the seat. This resulted in it not being possible to always extract the measure and not providing confidence in those measures which were extracted.	Elbow Rest Height should be taken manually in future surveys.

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
-	Sitting Eye Height	Manual	Sitting Eye Height was taken using the anthropometer. However, due to the helmet it was not possible to properly take this measure from the necessary angle which is required to minimise the potential of injury to the participant as the anthropometer arm is close to their eye during this measure.	Sitting Eye Height should be taken from a 3D scan.
DCC (SCE Two)				
EM06	Acromion Height	Manual (Anthropometer)	As the CWC jacket required compression to identify the point of the Acromion, Right, the measure was taken manually. There were no identified problems with this method.	Same as per pilot survey (manual).

Measure		Measurement Method	Rationale/Problems	Future Measurement Method
EM22	Acromion Height, Sitting	Manual (Anthropometer)	As the CWC jacket required compression to identify the point of the Acromion, Right, the measure was taken manually. A standard anthropometric box was used but due to the additional volume taken up by the encumbered participant it was sometimes difficult for the base of the anthropometer to be fully rested on the box which meant that the anthropometer wasn't as stable as it should have been. Additionally, as the anthropometer sat further away from the participant the measuring arms sometimes struggled to reach the desired landmark.	Same as per pilot survey (manual) but it is recommended that an anthropometric box with a larger surface area and an anthropometer with longer measuring arms be developed (Recommendation 1f).

6. PECCF Dataset

6.1 PECCFs

6.1.1 Use of PECCFs

The intent of a PECCF is to add the value to the relevant anthropometric measurement to give a total measurement for the encumbered user. So, firstly, if evaluating a design then the correct anthropometric measurement(s) should be identified. The decision on using either, or both, male or female anthropometric measurement should be made and the percentile value(s) to use should also be made. Then the relevant PECCF should be added to that value(s).

6.1.2 Single Data Set

The PECCFs were derived in two sets; female and male. However, for simplicity of application and due to minimal differences between the male and female PECCF datasets, the decision was made to present one single dataset where the PECCF value can be added to either male or female AWAS data. Although semi-nude data for one measure varies greatly between male and female, the same is not true for PECCFs for the same measure. The only PECCF which showed a large difference between males and females was Chest Circumference where the difference was approximately 50 mm in SCE One. However, in such an instance, by using the larger PECCF (the female) then the male PECCF is adequately bounded and so when space claims are made using the female PECCF added to potentially male 95^{th}%ile AWAS data then both males and females will be accommodated. Whichever data-point, male or female, presented the largest PECCF, this value was taken into the final, single data set.

6.1.3 Data set

Table 10 presents the PECCFs for all four role and ensemble conditions. Note this is only directly applicable to those clothing and equipment ensembles which were developed. If additional equipment or clothing/equipment is procured which is significantly different to that used in this survey then additional consideration should be given. For example, if a more bulky body armour was to be worn or arctic clothing then the PECCFs should be re-surveyed.

Table 10: Personal Equipment and Clothing Correction Factor (PECCF) Datasets for Dismounted Close Combatant (DCC) and Driver/Crew in SCE ONE and SCE TWO

MEASURES		DCC					Driver/Crew				
		SCE ONE			SCE TWO		SCE ONE:			SCE TWO	
		Male Correction Factor (mm)	Female Correction Factor (mm)	PECCF (mm)	Male Correction Factor (mm)	PECCF (mm)	Male Correction Factor (mm)	Female Correction Factor (mm)	PECCF (mm)	Male Correction Factor (mm)	PECCF (mm)
EM01	Stature	71	70	71	70	71	69	62	69	71	71
EM02	Weight	26	26	26	28	28	14	14	14	15	15
EM03	Head/Helmet Circumference	225	246	246	225	246	317	327	327	317	327
EM04	Head/Helmet Breadth	82	82	82	82	82	126	119	126	126	126
EM05	Head/Helmet Length	46	54	54	46	54	55	65	65	55	65
EM06	Acromion Height	53	57	57	44	57	53	57	57	36	57
EM07	Chest Circumference	418	471	471	427	471	154	186	186	169	186
EM08	Chest Breadth	12	24	24	25	25	17	18	18	14	18
EM09	Chest Depth	251	236	251	243	251	79	41	79	80	80
EM10	Waist Circumference (omphalion)	660	665	665	676	676	379	358	379	389	389
EM11	Buttock Circumference	47	61	61	101	101	47	61	61	101	101
EM12	Crotch Height	-36	-20	-36	-94	-94	-36	-20	-36	-102	-102
EM13	Hand Circumference	24	27	27	16	27	24	27	27	16	27
EM14	Hand Breadth	6	5	6	5	6	6	5	6	5	6
EM15	Hand Length	10	9	10	6	10	10	9	10	2	10
EM16	Hand Thickness	4	6	6	3	6	4	6	6	2	6
EM17	Ankle Height	39	46	46	39	46	39	46	46	39	46
EM18	Foot Breadth, Horizontal	9	9	9	9	9	9	9	9	9	9
EM19	Foot Length	45	36	45	45	45	45	36	45	45	45
EM20	Ball of Foot Length	17	11	17	17	17	17	11	17	17	17

MEASURES		DCC					Driver/Crew				
		SCE ONE			SCE TWO		SCE ONE			SCE TWO	
		Male Correction Factor (mm)	Female Correction Factor (mm)	PECCF (mm)	Male Correction Factor (mm)	PECCF (mm)	Male Correction Factor (mm)	Female Correction Factor (mm)	PECCF (mm)	Male Correction Factor (mm)	PECCF (mm)
EM21	Sitting Height	31	30	31	31	31	35	26	35	36	36
EM22	Acromion Height, Sitting	12	20	20	-1	20	12	20	20	9	20
EM23	Bideltoid Breadth	63	77	77	95	95	36	67	67	79	79
EM24	Forearm-Forearm Breadth	156	183	183	196	196	110	125	125	156	156
EM25	Abdominal Extension Depth, Sitting	266	263	266	272	272	80	86	86	91	91
EM26	Hip breadth, Sitting	15	27	27	39	39	15	27	27	47	47
EM27	Thigh Clearance	17	16	17	20	20	17	16	17	20	20
EM28	Knee Height, Sitting	73	73	73	73	73	73	73	73	73	73
EM29	Popliteal Height	36	43	43	26	43	36	43	43	26	43
EM30	Buttock-Knee Length	0	21	21	44	44	0	21	21	44	44
EM32	Buttock-Popliteal Length	9	-13	9	4	9	9	-13	9	4	9

7. DHM Evaluation

One of the types of assessment which requires encumbered anthropometric data is that of DHM evaluation. Measures which are required to conduct DHM evaluations were included in the pilot survey. As part of a separate project, the preliminary PECCF dataset were applied to a driver assessment using *Human Solutions - GmbH* RAMSIS software and consideration was given to the usability of the encumbered measures, see Figure 7. The outcome of this preliminary assessment was that a number of the encumbered measures were able to be used in the software, some measures required further modification to be of use in the software and additional measures which were required to fully 'encumber' the DHM will be required to be taken in future surveys.

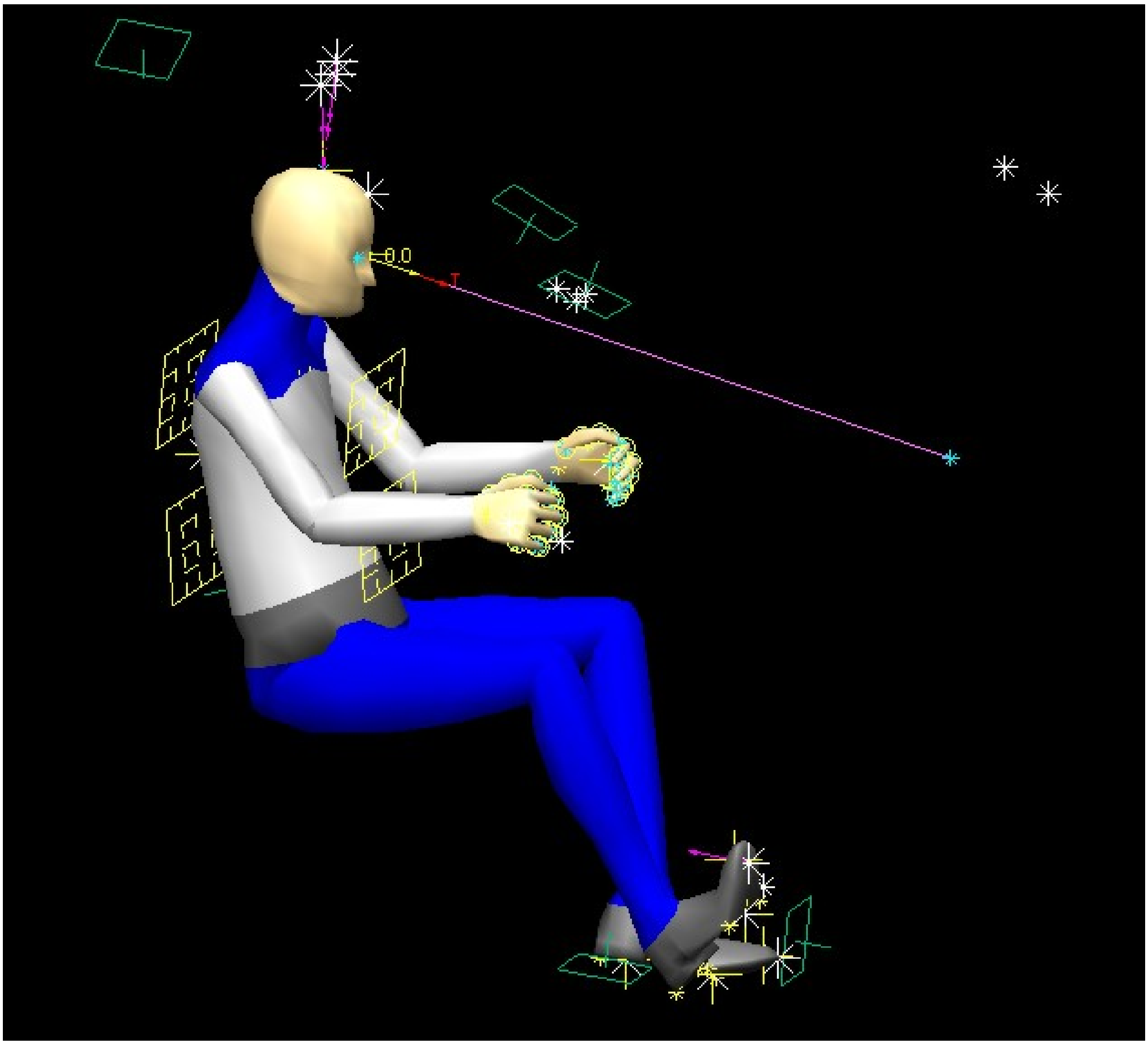

Figure 7: RAMSIS Evaluation

The measures which were directly applicable include:

1. **Buttock-Popliteal Length** is used to adjust the H point position horizontally;
2. **Bideltoid Breadth** where half of the PECCF is used as a clearance around the deltoid (task limit);
3. **Forearm-Forearm Breadth** where half of the PECCF is placed around the elbow as a clearance (task limit);
4. **Hip Breadth, Sitting** is used to offset a clearance (task limit) around the hips at seat level;
5. **Hand Breadth** where half of the PECCF is added as a clearance (task limit) around the hand;
6. **Hand Length** where half of the PECCF is added as a clearance (task limit) to front of the hand;
7. **Hand Thickness** where half of the PECCF is added as a clearance (task limit) around the hand;
8. **Helmet Breadth** is used as a clearance (task limit) around either side of the head;
9. **Helmet Length** is used as a clearance (task limit) around either side of the head;
10. **Thigh Clearance** is used as a clearance measurement along thighs;
11. **Knee Height, Sitting** has ankle height subtracted from the PECCF (to represent the shoe sole clearance) and added above the knee as a task limit;
12. **Ankle Height** to offset clearance (task limits) for pedals/floor to represent the shoe sole clearance;
13. **Foot Breadth, Horizontal** to offset clearance (task limit) for pedals/floor;
14. **Foot Length** offset clearance (task limit) for pedals/floor; and
15. **Ball of Foot Length** which allows for fore/aft position of foot length.

The measures which require modification are (Recommendation 1e):

1. **Chest Depth** is used as a clearance measurement fore/aft along the thoracal joint. Chest depth is applied to the front and rear of the manikin where 50% of the PECCF was added to the front and 50% of the chest depth PECCF was added to the rear. Future surveys should collect the PECCF for front chest depth and rear chest depth (as well as overall chest depth);
2. **Abdominal Extension Depth, Sitting** is used as a clearance measurement fore/aft along the thoracal joint. As with chest depth, abdominal extension depth, sitting, is applied to the front and rear of the manikin where 60% of the PECCF was added to the front and 40% to the rear. Future surveys should collect the PECCF for front abdominal extension depth, sitting and rear abdominal extension depth, sitting (as well as overall abdominal extension depth, sitting);
3. **Sitting Height** has acromion height, sitting deducted from the PECCF to provide the offset required above the head to account for the helmet. Future surveys should consider taking sitting height with helmet and sitting height (fully clothed) without the helmet to provide a more accurate offset required for the helmet;
4. **Buttock-Knee Length** has buttock-popliteal length subtracted to provide offset for in front of the knee and added as a task limit to driver's console. Future surveys should consider taking clothed buttock-semi-nude knee to provide a more accurate offset.

5. **Acromion Height, Sitting** is used to adjust the H point position vertically. Only 50% of the acromion height, sitting PECCF was applied as only the H point sits below the acromion. Future surveys should consider taking acromion height only with lower body clothing on and semi-nude acromion landmarks.

Measures which should be taken in future surveys (Recommendation 1d):

1. **Heel Height** to determine the offset for how high the heel is from the floor;
2. **Forefoot Height** to determine the offset for how high the forefoot is from the pedal; and
3. **Helmet with Night Vision Goggles (NVGs)** to determine the task limit around either side of the head when NVGs are worn.

8. Recommendations for Future Encumbered Anthropometric Surveys

8.1 Methodological Recommendations for Future Encumbered Anthropometric Surveys

Data Recording

Recommendation 1a: For future surveys the Excel spreadsheet used to collect the measurements should be iterated to make the spreadsheet useful for collection of encumbered measures. This would include, but is not limited to, the immediate calculation of the relevant PECCF (encumbered measure minus semi-nude measure), identifying if the difference between the first and second PECCF is acceptable or if a third measure is required and a sanity check to determine if the PECCF is realistic. The development of the spreadsheet will require the identification of acceptable percentages of difference between the first and second measures. This will allow for real-time exploration of any outliers and, hopefully, reduce the level of variance seen in the results of the pilot survey.

SCE Size Allocation

Recommendation 1b: Future surveys should ensure that all possible sizes of equipment and clothing are available and that allocation of the items to subject is based on the manufacturers' sizing guides and adequate fitting.

Reliability Testing

Recommendation 1c: It is recommended that, when future surveys are conducted, a greater number of participants are measured and analysis, such as Bland-Altman Analysis is conducted to allow for more in-depth analysis of the results. Bland-Altman Analysis, and other similar analyses, could not be reliably conducted on the data with only ten participants.

Additional Measures

Recommendation 1d: The analysis conducted has identified that there are a number of measures, which were not taken as part of this survey, which would be beneficial to take in future surveys. These measures are:

- **Waist Breadth** to determine the widest breadth on the torso;
- **Heel Height** to determine the offset for how high the heel is from the floor;
- **Forefoot Height** to determine the offset for how high the forefoot is from the pedal; and
- **Helmet with NVG and counterweights** to determine the offset around either side of the head when NVGs are worn.

Modification to Measures

Recommendation 1e: There are a number of measures which require modification in future surveys. Prior to use in future surveys, the modifications should be piloted to ensure that they are producing accurate and reliable results. These are:

- **Chest Depth** requires total, front and rear PECCF for DHM evaluation;
- **Abdominal Extension Depth, Sitting** requires total, front and rear PECCF for DHM evaluation;
- **Sitting Height** requires normal Sitting Height plus Sitting Height without helmet for DHM evaluation;
- **Buttock-Knee Length** requires normal Buttock-Knee Length plus clothed Buttock-Semi-Nude Knee for DHM evaluation;
- **Acromion Height, Sitting** requires normal Acromion Height, Sitting plus Acromion Height with only clothed lower body and semi-nude acromion landmarks for DHM evaluation; and
- **Ankle Height** requires a more effective landmark sticker for identification in 3D scans.

Measuring Equipment Modification

Recommendation 1f: The measuring equipment used to measure Stature, seated statures and breadths, such as Forearm-Forearm Breadth, required modification to improve the ease of taking those measures. To improve the accuracy of measuring Stature, it is recommended that a more secure, sturdy stadiometer is used and consideration given to moving the base of the stadiometer forward to allow the participant to stand straight (the increase in lateral, posterior bulk on the back of the participant caused by the wearing of body armour does not allow the participant to stand straight). To improve the accuracy of measuring seated height it is recommended that an anthropometric box with a larger surface area and an anthropometer with longer measuring arms be developed. Consideration should also be given to modifying the measuring equipment to help increase the accuracy of Acromion Height (standing and seated) for example, weighting the anthropometer to apply a consistent level of pressure to compress the clothing may be a solution.

8.2 Recommendations for Future Areas of Work Relating to Encumbered Anthropometry

Postural Change

Recommendation 2a: Due to the load which participants are required to wear during some of the encumbered conditions and the requirement to maintain a specific posture it was identified that they may be subject to postural fatigue and unintentionally alter their posture during measuring. This would lead to differences in the data. Although some anomalies in the data could be due to postural change, the results were not conclusive and so it is recommended that separate work be conducted, possibly including motion capture, to identify if postural fatigue impacts on encumbered anthropometric data collection.

TEM

Recommendation 2b: It is recommended that encumbered anthropmetric data be collected using multiple measurers and intra-measurer TEM is calculated and analysed to assess the reliability of such measures when using multiple measurers.

Compare Scans to Manual Measures

Recommendation 2c: One of the factors which impacted on the decision as to whether to take a measure manually or in the 3D scanner was whether compression was required. Wherever compression was required, the measure was taken manually. As taking measures from 3D scans reduces the amount of time a participant is required to wear the ensembles and observe specific postures it is beneficial to take as many measures as possible. It is, therefore, recommended that analysis be conducted to extract all those measures taken manually from the 3D scans and compare them. Should the results prove favourable then it may be possible to take more measures via the 3D scanner in future surveys.

Range of Motion

Recommendation 2d: Range of motion data is important and should be collected in a separate study as there are additional considerations and measurement methods to consider which could not be addressed in the pilot survey.

Additional SCE Conditions

Recommendation 2e: Due to the nature of a pilot survey it was not possible to test all SCE. Indeed, it will never be possible to test all SCE variations but work should be conducted to gather more data sets on other SCE which are likely to impact on occupant packaging. A key condition would be to test a DCC in a belt rig (i.e. Tier 0 Heavy, Belt). As the focus of operations is moving from being Afghanistan focused to near region (i.e. the jungle), the type of Load Carriage Equipment (LCE) and body armour is likely to change to more hip borne rather than shoulder/torso borne. Hip belts will have a large impact on occupant packaging and so should be subject to an encumbered anthropometric survey. Other SCE requirements should be considered and may include, although are not limited to:

- Gunners;
- Chemical and Biological (CB) Suits;
- Medics; and
- Signallers.

Sample Size

Recommendation 2f: A survey should be conducted with a much larger participant group and comparison between the results from the large group with the pilot survey data should be conducted to identify if there is a significant difference. This will help to determine what the required sample size is for future surveys.

9. References

[1] Niels Diffrient, Alvin R. Tilley and Joan Bardagjy (1974) *Human Scale One/Two/Three* The MIT Press

[2] Carrier, R, & Meunier, P (1996) *Effects of Protective Equipment on Anthropometric Measurements and Functional Limitations* Defence and Civil Institute of Environmental Medicine, No.96-CR-22.

[3] Paquette, S.P., Case, H.W, Annis., J.F., Mayfield, T.L., Kristensen, S. and Mountjoy, D.N (1999) *The Effects of Multilayered Military Clothing Ensembles on Body Size: A Pilot Study* U.S Army Solider and Biological Chemical Command Soldier Systems Centre, Natick/TR-99/012

[4] Dreyfuss, H. & Tilley, A.R. (2002) *The Measure of Man and Woman: Human Factors in Design* John Wiley & Sons, Inc.

[5] Military Standard 1472F (2003) *Human Engineering*.

[6] Pheasant, S. & Haslegrave, C.M. (2006) *Bodyspace: Anthropometry, Ergonomics and the Design of Work* Tayolr & Francis

[7] Oudenhuijzen, A.J.K, Zehner, G, and Hudson, J (2008) *Dutch Anthropometry for Vehicle Design and Evaluation* TNO-DV 2008 A211

[8] Ministry of Defence: Defence Standard 00-250, Issue 1, 23rd May 2008. *Human Factors for Designers of Systems, Part 3: Technical Guidance. Section 9: People Characteristics.*

[9] *Pilot Study of Firefigher Three-Dimensional Anthropometry to Improve Seatbelt Safety* (2008) National Institute of Standards and Technology, U.S. Department of Commerce

[10] ADF Anthropometric Survey (2012): Landmarking and Measurement Manual.

[11] Tomkinson, G., Dale, M., & Bowler, T. *Validation Trial Report* Adelaide, SA: University of South Australia

[12] Perini, T.A., de Oliveria, G.L., dos Santos Ornellas, J., and de Oliveria, F.P (2005) *Technical Error of Measurement in Anthropometry*, Sociedade Brasileira de Medicina do Esporte, Vol. 11, No 1 – Jan/Feb.

[13] Norton, I. N, Olds, T and Australian Sports Commission (1996) *Anthropometrica: A Textbook of Body Measurement for Sports and Health Course* USNW Press

BS EN ISO 15535:2006 General Requirements for Establishing Anthropometric Databases 2007

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Appendix A Encumbered Anthropometric SCE Items

Table A-1: Encumbered Anthropometric Soldier Combat Ensembles.

Item & Insert	Picture	Additional Information
DCC (SCE One)		
Crye Precision Combat Uniform (CPCU) Shirt (1) Insert: 2 x elbow pads		Pockets to be empty and closed.
CPCU Pants (1) Insert: 2 x knee pads		Pockets to be empty and closed. Leg bottoms should be tightened and bunched on top of boots.

Item & Insert	Picture	Additional Information
TBAS **Tier 2** (1) Range of TBAS pouches: • Double Magazine Pouch (1) • Triple Magazine Pouch (1) • Grenade Pouch (2) • Smoke Grenade Pouch (1) • MBITR pouch (1) • Medium Admin Pouch (1) • SPR Pouch (1) • Tourniquet (1) • Medical Pouch (1) • Dump Pouch (1) • Camelbak Pouch (1) Insert: training plates (size and weight of ballistic plates)		Shoulder straps and cummerbund adjusted to correct fit for each participant. All pouches to be filled and closed. Camelbak to be filled and strap/nozzle to sit over left shoulder.
ECH with VAS Shroud (1)		Helmet straps adjusted to fit subject.

Item & Insert	Picture	Additional Information
ActivArmr™ Patrol Gloves (1 pair)		Gloves to be worn under arms of CPCU shirt.
Redback Terra Combat Boot (1 pair)		Participants will be advised to wear their own thick socks.
Vehicle Crew (SCE One) - As DCC (SCE One) with the following modifications:		
TBAS **Tier 3** (1) Insert: Training plates (size and weight of ballistic plates)	   	Shoulder straps and cummerbund adjusted to correct fit for each participant.
Clean skin TBAS bar Tourniquet (1) and Medical Pouch (1)		Medical pouches to be filled and closed

Item & Insert	Picture	Additional Information
CVC Helmet (1) Insert: Communications head-set insert		Helmet straps adjusted to fit subject.
DCC and Vehicle Crew (SCE Two) As per DCC and Vehicle Crew (SCE One) with the addition of:		
CWC Jacket (1)		Velcro round jacket wrist should be tightened.

Item & Insert	Picture	Additional Information
CWC Pants (1)		Velcro round bottom of pant leg should be tightened.
CWC Gloves (1 pair)		Gloves to be worn under arms of CPCU shirt.

Appendix B SCE Conditions

Figure B-1: DCC (SCE One)

Figure B-2: Vehicle Crew (SCE One)

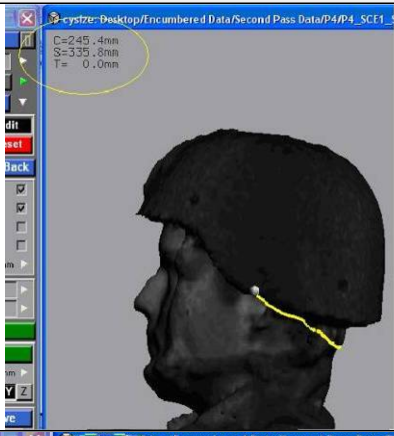
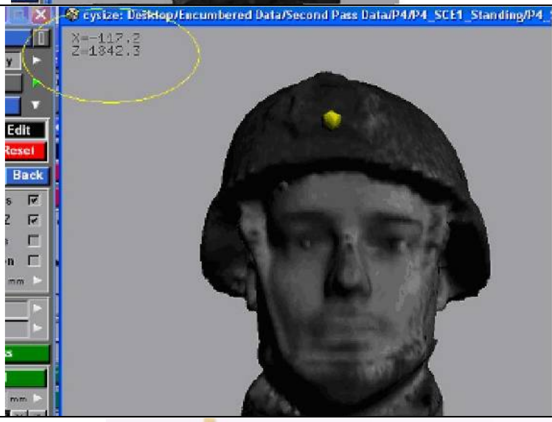
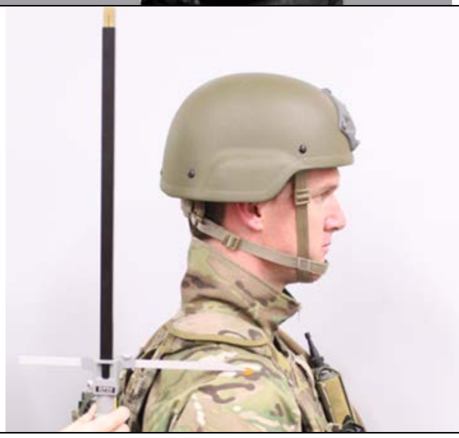
Figure B-3: DCC (SCE Two)

Figure B-4: Vehicle Crew (SCE Two)

Appendix C Encumbered Anthropometric Measurement Definitions

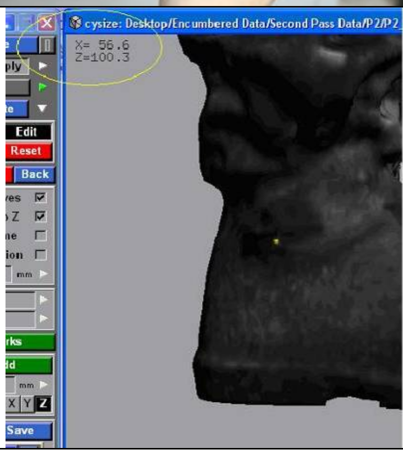
Table C-1: Encumbered Anthropometric Measurement Definitions and Pictures.

Measure		Encumbered Definition	Encumbered Picture
EM01	Stature	The vertical distance between the standing surface and the Top of the Helmet.	
EM02	Weight	The mass of the subject wearing clothing and equipment to the nearest 0.1 kg.	*Calculation – no picture*
EM03	Helmet Circumference	The circumference of the helmet is calculated by πd where 'd' is the Helmet Breadth (EM04) or Length, (EM05) whichever is larger.	*Calculation – no picture*

Measure		Encumbered Definition	Encumbered Picture
EM04	Helmet Breadth	The point-to-point distance between the most Left (lateral) and Right (lateral) points on the Helmet.	
EM05	Helmet Length	The point-to-point distance between the most anterior point on the front of the Helmet and the point on the back of the Helmet at the same level.	
EM06	Acromion Height	Standing surface to clothed Acromion, Right.	

Measure		Encumbered Definition	Encumbered Picture
EM07	Chest Circumference	The circumference of the clothed chest at the height of the point of the anterior Chest Depth measurement (EM10) following the most posterior and distal points of the clothing/equipment.	
EM08	Chest Breadth	The maximum horizontal breadth at the height of the compressed under-arm seam.	
EM09	Chest Depth	The horizontal distance between the most anterior point of clothing/equipment at approximate chest level.	

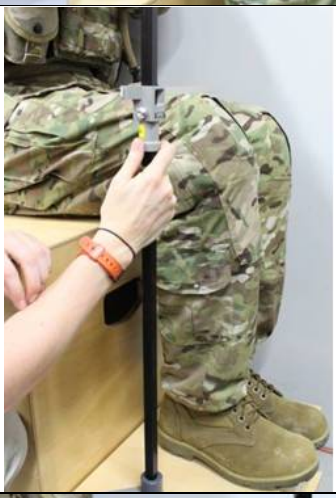
Measure		Encumbered Definition	Encumbered Picture
EM10	Waist Circumference	The circumference of the clothed waist at the most anterior point of clothing/equipment at the point of the Abdominal Extension Depth (EM27) and the point on the back at the same level.	
EM11	Buttock Circumference	The horizontal circumference of the torso at the height of the clothed Buttock Point, posterior.	
EM12	Crotch Height	Standing surface to crotch seam of pants.	
EM13	Hand Circumference	The circumference around the hand that passes over the clothed Metacarpale, II and the clothed Metacarpale, V landmarks.	

Measure		Encumbered Definition	Encumbered Picture
EM14	Hand Breadth	The distance between the clothed Metacarpale, II and the clothed Metacarpale, V landmarks.	
EM15	Hand Length	The distance between the clothed Centre Wrist Marker and clothed Dactylion, III landmarks.	
EM16	Hand Thickness	The distance between the clothed lateral points of the clothed Metacarpale, II.	
EM17	Ankle Height	The vertical distance between the standing surface and the clothed Lateral Malleolus landmark.	

Measure		Encumbered Definition	Encumbered Picture
EM18	Foot Breadth, Horizontal	The maximum horizontal distance between the clothed First Metatarsophalangeal Protrusion and clothed the Fifth Metatarsophalangeal Protrusion at the distal edges of the sole of the boot.	
EM19	Foot Length	The distance between the clothed Acropodion and the clothed Pternion landmarks at the most posterior and anterior edges of the sole of the boot.	
EM20	Ball of Foot Length	The distance along a line between the clothed Acropodion and Pternion between the Pternion and intersection of a line drawn through the First Metatarsophalangeal Protrusion landmark perpendicular to the line between Acropodion and Pternion.	

Measure		Encumbered Definition	Encumbered Picture
EM21	Sitting Height	The vertical distance between the sitting surface and Top of the Helmet.	
EM22	Acromion Height, Sitting	Sitting surface to clothed Acromion, Right.	
EM23	Bideltoid Breadth	The most lateral points on the clothed left and right upper arms. *Note that the breadth may not be taken directly on the deltoid but it is taken at the widest part as it is the largest distance which is of importance.*	

Measure		Encumbered Definition	Encumbered Picture
EM24	Forearm-Forearm Breadth	The maximum horizontal distance between the most lateral points on the clothed right and lateral left forearms (to the most distal point of the elbow pads).	
EM25	Abdominal Extension Depth, Sitting	The horizontal distance between the most anterior point of clothing/equipment at approximate waist level, and the point on the back at the same level. *When wearing body armour the Abdominal Extension Depth point is the most anterior point and so the circumference, taken at this point, represents the largest possible circumference in the waist area.*	
EM26	Hip Breadth	The maximum breadth of the seated subject at the clothed hip or thigh, whichever is larger.	

Measure		Encumbered Definition	Encumbered Picture
EM27	Thigh Clearance	Sitting surface to clothed Thigh Point, Top.	
EM28	Knee Height, Sitting	Footrest surface to superior point of clothed knee or top of the knee pad.	
EM29	Popliteal Height	Footrest surface to the clothed Dorsal Juncture of Calf and Thigh.	

Measure		Encumbered Definition	Encumbered Picture
EM30	Buttock-Knee Length	The horizontal distance between the clothed Buttock Point, Posterior and the clothed Knee Point, Anterior.	
EM31	Buttock-Popliteal Length	The horizontal distance between the clothed Buttock Point, Posterior and the clothed Knee Point, Anterior.	

Appendix D Encumbered Anthropometric Pilot Survey Brief

Purpose

The objective of this pilot encumbered anthropometric survey is to collect anthropometric measurements from semi-nude and clothed subjects. The results of this pilot survey will be used to provide preliminary data for military design projects and to develop a robust methodology for further surveys.

Anonymity

The researchers will not collect any demographic data from you which will identify you. Although the scan data will contain facial features this information will never be provided to those external to the research team unless consent is provided by you, the subject.

Method

During the course of the study you will be asked by the researchers to undress down to your underwear and a researcher will then palpate areas of the body to identify landmarks which will be marked with either a sticker or a small prism. The researcher will then take manual measurements with a variety of anthropometric measuring tools. Subsequently, you will be scanned using the 3D laser body scanner. The scanner is safe for human use and does not pose any side effects. You will then be asked to dress in SCE and the same activities will be conducted for you as a clothed subject i.e. land marking, manual measurements and scanning.

Appendix E Ethical Consent Form

Information and Consent Sheet

GENERAL ANTHROPOMETRY

Brief description of the Study.

This study is collecting anthropometric (body size) measurements in order to inform clothing and equipment sizing and design. Our aim is to use this data for current equipment acquisition and, with your consent, to develop a database of anthropometric data from the ADF population to ensure future equipment and clothing equipment is closely aligned with the body shape/size of current ADF personnel. Such use involves computation of distributions of various measures across the ADF population and the derivation of various statistics such as means, standard deviations, percentiles, medians, etc. to guide selection of clothing and personal equipment sizes to achieve better fits and reduce costs associated with overstocking and inappropriate numbers of purchased items of various sizes. The anthropometric data may also be used to better specify the size of working spaces – such as in vehicles where the ADF has some control of workspace design (e.g. M113 upgrade in the past).

Your part in the Study.

Participation in the study is entirely voluntary; there is no obligation to take part in the study, and if you choose not to participate there will be no detriment to you career or future health care;

- You may withdraw at any time with no detriment to your career or to your future health care;
- You will be given the opportunity to ask questions at any time, and all of your concerns will be addressed.
- On duty. Australian Defence Force members will be considered 'on duty' during participation.
- We are asking for up to 45 minutes of your time to take a number of measurements of your body size and shape. The following basic demographic information may also be recorded: sex, month and year of birth, country of birth, education level, service, and your current trade (your name will not be recorded). We require this demographic information to ensure the survey sample accurately reflects the current Australian Defence Force population. The measurements and techniques may vary in different investigations, but as a general rule will fall into the following categories:
    - Height and weight
    - Breadths, such as wrist breadth and shoulder breadth

- Circumferences, such as arm, hip, waist and chest
- Skinfold thicknesses, such as upper arm and back.
- 3 dimensional body scans. The scanning system uses an eye-safe class 1 visible red laser light to capture a highly accurate 3 dimensional digital statue (point cloud) of the surface of your body. This digital statue is identifiable as you. The laser passes over your body from head to toe in about 10 seconds. A technician (potentially of the opposite sex) will then use special software to closely examine the digital statue to identify key points on the body and extract body dimensions.

- We are also seeking your consent to use the data we collect from you for any future research beyond the current, specific study for the purposes described in the opening paragraph. Such further use would be such that there would be no stored data that allows association of an individual with the specific stored data items.

Supervision/Chaperoning

Measurements will be made carefully in a quiet room without due haste and the presence of unnecessary people. A second observer of the same sex as you (chaperone) will always be present. The measurer may be of either sex. If you prefer the measurer to be of a particular sex, efforts will be made to accommodate your wish. If this is not possible, you may withdraw consent to participate without detriment to your career or future health care. You may also nominate to have a friend/colleague (of either sex) present during measurements if you desire.

You will usually be barefooted or in thin socks. Undressing down to underclothes may be necessary so that the positioning of the body can be seen and the anatomical landmarks may be palpated, identified and marked. Marking the measurement sites and applying the measurement instruments will usually require manual contact. All measurements will be taken either sitting or standing.

All individuals taking these measurements have experience in the acquisition of anthropometric data. All measurements will be made according to accepted and widely published techniques.

Risks of participating

It is important to point out to you that there will be a number of risks associated with participation in this study. However, as you would expect, a range of safeguards have been put in place to make sure that these risks will be minimised.

The first risk is that you feel that you are being coerced or forced to participate in this study. In order to minimise the potential for coercion, recruitment of participants will be conducted by a person who

is not in your direct chain of command. As mentioned above, you will also be formally notified of your freedom to withdraw at any time should you change your mind about participating in this study.

Manual measurement techniques should place you at the most in minimal discomfort. You may experience slight pinching of the skin during skinfold measurements, and when circumference measurements are being taken. All measurements will be taken in accordance with accepted and widely published techniques. Potentially, 3 dimensional laser scanning may also be used. The 3 dimensional laser scanning system uses an eye-safe class 1 visible red laser light to capture a highly accurate 3 dimensional digital statue of the surface of your body. This digital statue is identifiable as you. Special software is then used to extract body dimensions from the scan. Physical manikins can be created from the scans to support the design of clothing and protective equipment.

Statement of Privacy
There is a separate risk associated with protecting your privacy. There is a risk that the data collected may be used inappropriately within Defence or within the wider community. An examples of this may include quoting your individual results in a Defence report. These risks will be reduced by the following:

- For the current, specific study, a code number will be designated to each volunteer (we will not record your name).
- With your permission, your data will subsequently be entered into a developing database of anthropometric data of ADF personnel. None of this data will be linked to your code number from the current, specific study. That is, you will not be identifiable in the enduring database.
- Only group data summaries will be used in any reports
- All original data will be kept under lock and key at the Defence Science & Technology Organisation (DSTO) for a period of at least five years.
- Secure information disposal methods will be used such as document shredding.
- The data will only be used for the purposes outlined above with your express permission.

On duty

All members of the Australian Defence Force who volunteer for this study will be considered to be on duty when participating in the study.

Names of Investigators

Chief Investigators:

1. Ms Renee Attwells
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8. Dr Nathan Daniell
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9. Ms Amy Simpson
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10. Ms Alison Fogarty
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Defence Science and Technology Organisation (DSTO)
506 Lorimer St, Fishermans Bend, Melbourne VIC 3207
T: (03) 9626 8656
F: (03) 9626 7830
E: Alison.Fogarty @dsto.defence.gov.au

Should you have any complaints or concerns about the manner in which this project is conducted, please do not hesitate to contact the researchers in person, or you may prefer to contact the Australian Defence Human Research Ethics Committee at the following address:

Executive Secretary
Australian Defence Human Research Ethics Committee
CP2–7–124
Department of Defence
CANBERRA ACT 2600
Telephone: (02) 6266 3837
Facsimile: (02) 6266 4068
Email: ADHREC@defence.gov.au

CONSENT

GENERAL ANTHROPOMETRY

I,..………………….. give my consent to participate in the project mentioned above on the following basis:

I have had explained to me the aims of this research project, how it will be conducted and my role in it.

I understand the risks involved as described above.

I am cooperating in this project on condition that:
the information I provide will be kept confidential

- the information will be used for this project and will be added to a developing and enduring database of anthropometric data of ADF personnel and may be used in this format for future research aimed at ensuring that future equipment and clothing is closely aligned with the body shape/size of current ADF personnel.
- the research results will be made available to me at my request and any published reports of this study and enduring anthropometric database will preserve my anonymity.

This survey may use 3D laser scanning. 3D scan data can be used to create a virtual image of the subject that may be used for reports and presentations, therefore if these images are used you may be identifiable (see next page for example image). Furthermore, 3D scan data can be used to create physical manikins to support the design of clothing and protective equipment, therefore if these manikins are used you may be identifiable (see next page for example torso manikin). If 3D scans are being taken please sign and date one of the following options:

OPTION 1: I GIVE permission for the researchers to use 3D scan images and create physical manikins that may identify me.

……………………… …………………………
Sign Date

OPTION 2: I GIVE permission for the researchers to use 3D scan images and create physical manikins only if I CANNOT be recognised in the image or manikin (thus de-identifying me).

……………………… …………………………
Sign Date

OPTION 3: I DO NOT give permission to use my 3D scan data to create images or manikins.

……………………… …………………………
Sign Date

Example Torso Manikin.

Example 3D Scan

I understand that:

- there is no obligation to take part in this study,
- if I choose not to participate there will be no detriment to my career or future health care
- I am free to withdraw at any time with no detriment to my career or future health care

I have been given a copy of the information/consent sheet, signed by me and by the principal researcher (name) to keep.

I have also been given a copy of ADHREC's *Guidelines for Volunteers*.

____
Signature of Volunteer

____
Name in Full

____
Date

____
Signature of Researcher

____
Name in Full

____
Date

Survey ID Number ________________

Should you have any complaints or concerns about the manner in which this project is conducted, please do not hesitate to contact the researchers in person, or you may prefer to contact the Australian Defence Human Research Ethics Committee at the address detailed on page 3.

Appendix F 3D Scan Measurement Extraction

F.1. File Conversion

The measures to be taken from 3D scans require processing to allow for manual measurement extracted in a software programme. The steps required are as follows:

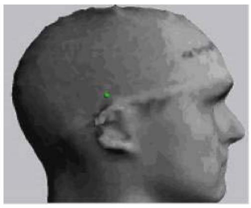
1. Save the scan in greyscale and with *Point Color To Texture* as an obj. file using *ScanworX* Editor (*Human Solutions,* Kaiserslautern, Germany).
2. Convert the obj. file to a ply. format using *PlyTool+*.
3. Open the file in *CySlice* and extract measures.

F.2. Semi-Nude Measurements (Standing)

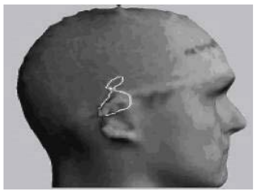
F.2.1 Head Breadth

[1] Zoom in and re-orientate the head to clearly see the most lateral part of the right side of the head.

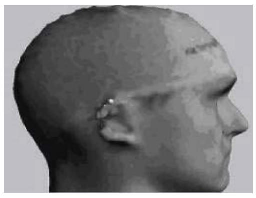
[2] Place a digital landmark above the right ear and press 'space' to de-activate the landmark.



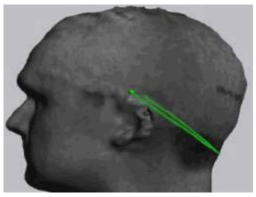
[3] Select 'Axis' and 'Y', click 'add' and then click on the digital landmark.



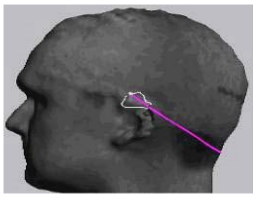
[4] Move the digital landmark (by holding the 'control' key and the middle mouse button) until the white guideloop created by the Y-line disappears, this will be the Head Breadth Marker, Right landmark (the most lateral point above the right ear).



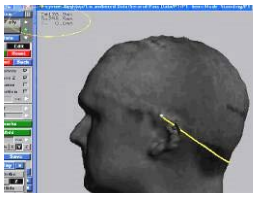
[5] Activate the digital landmark by holding the 'control' key and pressing the left mouse button.



[6] Rotate the head and place a digital landmark above the left ear.



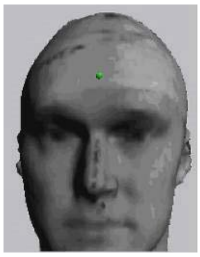
[7] Press the 'space' to deactivate left side digital landmark and, using the Y axis, move it to the most lateral part of the left side of the head. This will be the Head Breadth Marker, left landmark (the most lateral point above the left ear).



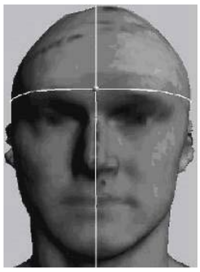
[8] Place the cursor over the line and press the "i" key on the keyboard.

[9] Record the "C" distance as this is the point-to-point measurement.

F.2.2 Head Length



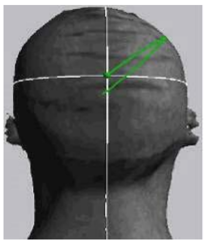
[1] Place a digital landmark around the point of the glabella and deactivate the digital landmark by pressing 'space'.



[2] Add a 'Z" axis by selecting 'Axis' and 'Z', clicking 'add' and then clicking on the digital landmark.

[3] Add a 'Y" axis by selecting 'Axis' and 'Y', clicking 'add' and then clicking on the digital landmark. This will create a YZ crosshair.

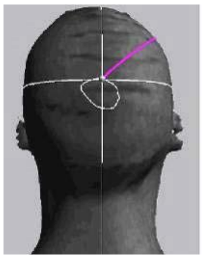
[4] Move the digital landmark until, from a front view, the vertical line bisects the face and, from a side view, the horizontal line runs across the most anterior part of the frontal bone. This is the point of the glabella.
[5] Activate the digital landmark and then rotate to a rear view.



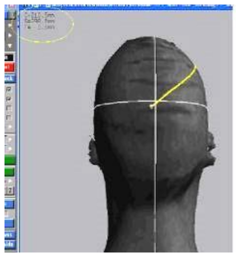
[6] Place a digital landmark around the point of the opisthacranion and deactivate the landmark.

[7] Add an 'x' axis and move the digital landmark (by holding the 'control' key and the middle mouse button) until the white guideloop created by the X-line disappears, this will be at the

opisthacranion.

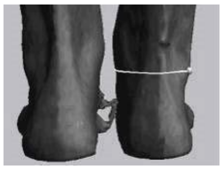


[8] Place the cursor over the line and press the “i” key on the keyboard.



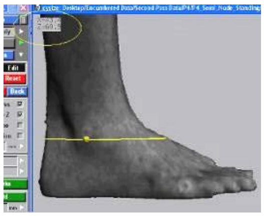
[9] Record the “C” distance as this is the point-to-point measurement.

F.2.3 Ankle Height



[1] Place a digital landmark in the centre of the sticker on the Lateral Malleolus landmark.

[2] Create a 'z' axis guideline and ensure the digital landmark is central to the Lateral Malleolus. Adjust the digital landmark accordingly, without altering its height.

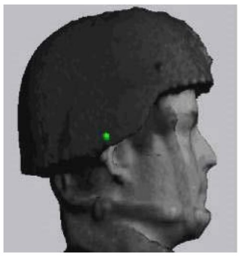


[3] Hover the cursor over the point and press "I" on the keyboard.

[4] Record the 'Z' value displayed on the screen as this indicates the height of the ankle.

F.3. DCC (SCE One) Encumbered Measurements (Standing)

F.3.1 Helmet Breadth

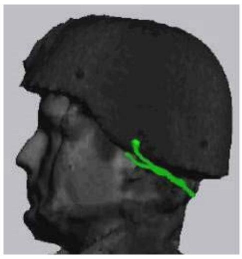


[1] Zoom in and re-orientate the head to clearly see the most lateral part of the right side of the head.

[2] Place a digital landmark on the right ear cup and press 'space' to de-activate the landmark.

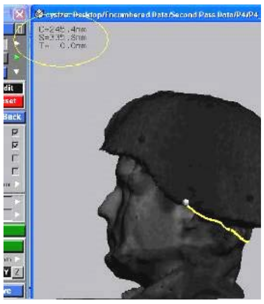
[3] Select 'Axis' and 'Y', click 'add' and then click on the digital landmark.

[4] Press 'space' and move the digital landmark (by holding the 'control' key and the middle mouse button) until the white guideloop created by the Y-line disappears, this will be the most later point of the right side of the helmet.



[5] Activate the digital landmark by holding the 'control' key and pressing the left mouse button.

[6] Rotate the head and place a digital landmark on the left ear cup.



[7] Press the 'space' to deactivate left side digital landmark and, using the Y axis, move it to the most lateral point of the left side of the helmet.

[8] Place the cursor over the line and press the "i" key on the keyboard.

[9] Record the "C" distance as this is the point-to-point measurement.

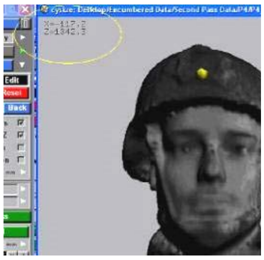
F.3.2 Helmet Length

[1] Place a digital landmark at the most anterior point on the helmet and deactivate the digital landmark by pressing 'space'.

[2] Add an 'X" axis by selecting 'Axis' and 'X', clicking 'add' and then clicking on the digital landmark.

[3] Press 'space' and move the digital landmark (by holding the 'control' key and the middle mouse button) until the white guideloop created by the X-line disappears, this will be the most lateral point.

[4] Place the cursor over the line and press the "i" key on the keyboard.



[5] Record the "X" measurement.

[6] Perform the same steps for the most posterior point on the helmet and record the 'X' measurement.

[7] Determine the helmet length by calculating the difference between the X-axis coordinates for the most anterior and most posterior point of the helmet.

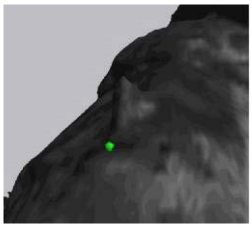
F.3.3 Head Circumference

Use the head breadth or head length, whichever is that larger and calculate the circumference using the following calculation:

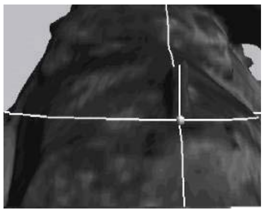
$C= \pi d$ where d is the head breadth or head length (diameter)

F.3.4 Acromial Height

[1] Place a digital landmark at the distal base of the Raised Physical Landmark at Acromion, Right.

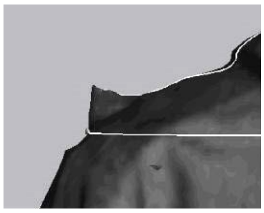


[2] Add a 'Z" axis by selecting 'Axis' and 'Z', clicking 'add' and then clicking on the digital landmark.



[3] Add a 'X" axis by selecting 'Axis' and 'X', clicking 'add' and then clicking on the digital landmark. This will create a XZ crosshair.

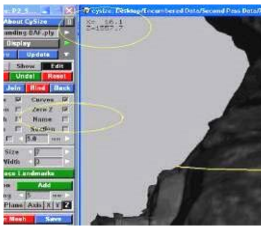
[4] Rotate to a lateral view and align the vertical line such that it bisects the Raised Physical Landmark at Acromion, Right.



[5] Rotate to a front or rear later view, whichever allows best visualisation of the height of the Acromion, Right landmark.

[6] Move the digital landmark (by holding the 'control' key and the middle mouse button) until the horizontal line is aligned at the distal base of the Raised Physical Landmark.

[7] Ensure that the ''Zero Z' button is ticked on the CySlice menu.

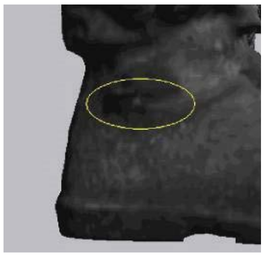


[8] Hover the cursor over the point and press "I" on the keyboard.

[9] Record the 'Z' value displayed on the screen as this indicates the height of the acromion.

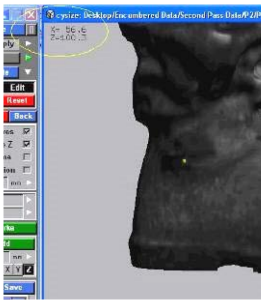
F.3.5 Ankle Height

[1] Re-orientate and zoom in on a lateral view and place a digital landmark on the Vicon marker on the Lateral Malleolus landmark.



[2] Hover the cursor over the point and press “I” on the keyboard.

[3] Record the ‘Z’ value displayed on the screen as this indicates the height of the ankle.



F.4. DCC (SCE One) Encumbered Measurements (Sitting)

F.4.1 Acromion Height, Sitting

Follow instructions for standing Acromion Height using the seated scan.

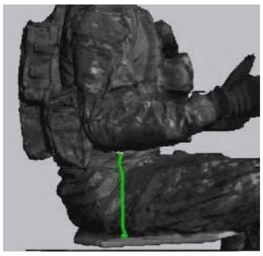
F.4.2 Elbow Rest Height

[1] Zoom in and re-orientate so that you can clearly see the bottom of the clothed Olecranon, Bottom.

[2] Place a digital landmark on the inferior clothed Olecranon, Bottom.

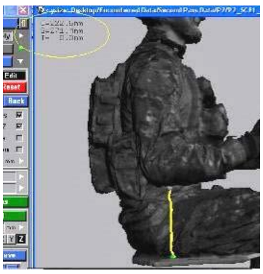
[3] Add a 'Z' axis guideline and move the digital landmark (by holding the 'control' key and the middle mouse button) until the white guideloop created by the Z-axis disappears, this will be the most inferior point of the clothed Olecranon, Bottom.

[4] Activate the digital landmark by holding the 'control' key and pressing the left mouse button.
[5] Place a point on the superior point on the sitting surface, directly under the Olecranon point.



[6] Hover the cursor over the point and press "I" on the keyboard.

[7] Record the "C' value as this is the point-to-point distance.



F.5. Vehicle Crew (SCE One) Encumbered Measurements (Standing)

F.5.1 Helmet Circumference

Follow instructions for Helmet Circumference using the most lateral points of the left and right side of the CVC helmet.

F.5.2 Helmet Breadth

Follow instructions for SCE One DCC Helmet Breadth using the most lateral points of the left and right side of the CVC helmet.

F.5.3 Helmet Length

Follow instructions for Helmet Circumference using the most lateral points of the left and right side of the CVC helmet.

Appendix G Sample Size Calculations

Table G-1: Sample Size for all conditions with 1% precision, 95% confidence

Measure		1% precision, 95% confidence					
		AWAS	Semi-Nude	DCC (SCE One)	Vehicle Crew (SCE One)	DCC (SCE Two)	Vehicle Crew (SCE Two)
EM01	Stature	185	328*	303	132	108	39
EM06	Acromion Height	215	288	263	-	131	-
EM07	Chest Circumference	626	330	43	140	140	51
EM08	Chest Breadth	750	652	400	374	107	96
EM09	Chest Depth	843	362	143	599	300	110
EM10	Waist Circumference (Omphalion)	1070	61	15	80	46	79
EM11	Buttock Circumference	441	93	51	-	52	-
EM12	Crotch Height	240	585	315	-	160	-
EM13	Hand Circumference	400	652	326	-	261	-
EM14	Hand Breadth	369	671	544	-	351	-
EM15	Hand Length	372	342	347	-	24	-
EM16	Hand Thickness		966	613	-	1113	-
EM17	Ankle Height	1111	904	286	-	286	-
EM18	Foot Breadth, Horizontal	426	1345	1161	-	1161	-
EM19	Foot Length	305	541	510	-	510	-
EM20	Ball of Foot Length	369	701	706	-	706	-
EM21	Sitting Height	162	337	305	281	118	81
EM22	Acromion Height, Sitting	252	329	197	-	59	-
EM23	Bideltoid Breadth	433	511	756	97	13	160
EM24	Forearm-Forearm Breadth	979	741	182	361	224	20
EM25	Abdominal Extension Depth, Sitting	1561	445	51	263	86	374
EM26	Hip Breadth, Sitting	625	395	195	-	172	-
EM27	Thigh Clearance	741	665	586	-	345	-
EM28	Knee Height, Sitting	294	384	349	-	182	-
EM29	Popliteal Height	321	613	671	-	252	-
EM30	Buttock-Knee Length	232	257	225	-	319	-
EM31	Buttock-Popliteal Length	263	264	501	-	513	-

*The largest sample size requirements for each measure are highlighted.

Table G-2: Sample Size Calculations for DCC (SCE One)

Measure		CV	Sample Size (DCC, SCE One)			
			1% precision, 95% confidence	2% precision, 95% confidence	1% precision, 90% confidence	2% precision , 90% confiden ce
EM01	Stature	5.79	303	76	214	53
EM03	Head Circumference	4.31	168	42	118	30
EM04	Head Breadth	2.63	62	16	44	11
EM05	Head Length	4.37	172	43	122	30
EM06	Acromion Height	5.39	263	66	185	46
EM07	Chest Circumference	2.18	43	11	30	8
EM08	Chest Breadth	6.65	400	100	282	70
EM09	Chest Depth	3.98	143	36	101	25
EM10	Waist Circumference (Omphalion)	1.29	15	4	11	3
EM11	Buttock Circumference	2.38	51	13	36	9
EM12	Crotch Height	5.91	315	79	222	56
EM13	Hand Circumference	6.01	326	82	230	57
EM14	Hand Breadth	7.75	544	136	383	96
EM15	Hand Length	6.19	347	87	244	61
EM16	Hand Thickness	8.23	613	153	432	108
EM17	Ankle Height	5.63	286	72	202	50
EM18	Foot Breadth, Horizontal	11.33	1161	290	818	204
EM19	Foot Length	7.51	510	127	359	90
EM20	Ball of Foot Length	8.84	706	177	497	124
EM21	Sitting Height	5.80	305	76	215	54
EM22	Acromion Height, Sitting	4.67	197	49	139	35
EM23	Bideltoid Breadth	9.14	756	189	532	133
EM24	Forearm-Forearm Breadth	4.49	182	45	128	32
EM25	Abdominal Extension Depth, Sitting	2.37	51	13	36	9
EM26	Hip Breadth, Sitting	4.65	195	49	138	34
EM27	Thigh Clearance	8.05	586	146	413	103
EM28	Knee Height, Sitting	6.21	349	87	246	61
EM29	Popliteal Height	8.61	671	168	472	118
EM30	Buttock-Knee Length	4.99	225	56	158	40
EM31	Buttock-Popliteal Length	7.44	501	125	353	88

Table G-3: Sample Size Calculations for Vehicle Crew (SCE One)

Measure		CV	Sample Size (Vehicle Crew, SCE One)			
			1% precision, 95% confidence	2% precision, 95% confidence	1% precision, 90% confidence	2% precision, 90% confidence
EM01	Stature	3.82	132	33	93	23
EM03	Head Circumference	4.34	170	43	120	30
EM04	Head Breadth	4.34	170	43	120	30
EM05	Head Length	2.63	62	16	44	11
EM07	Chest Circumference	3.94	140	35	99	25
EM08	Chest Breadth	6.43	374	93	263	66
EM09	Chest Depth	8.14	599	150	422	105
EM10	Waist Circumference (Omphalion)	2.98	80	20	56	14
EM21	Sitting Height	5.57	281	70	198	49
EM23	Bideltoid Breadth	3.27	97	24	68	17
EM24	Forearm-Forearm Breadth	6.32	361	90	255	64
EM25	Abdominal Extension Depth, Sitting	5.39	263	66	185	46

Table G-4: Sample Size Calculations for DCC (SCE Two)

Measure		CV	Sample Size (DCC, SCE Two)			
			1% precision, 95% confidence	2% precision, 95% confidence	1% precision, 90% confidence	2% precision, 90% confidence
EM01	Stature	3.46	108	27	76	19
EM03	Head Circumference	4.31	168	42	118	30
EM04	Head Breadth	2.63	62	16	44	11
EM05	Head Length	4.37	172	43	122	30
EM06	Acromion Height	3.80	131	33	92	23
EM07	Chest Circumference	3.93	140	35	98	25
EM08	Chest Breadth	3.45	107	27	76	19
EM09	Chest Depth	5.76	300	75	211	53
EM10	Waist Circumference (Omphalion)	2.26	46	12	33	8
EM11	Buttock Circumference	2.40	52	13	37	9
EM12	Crotch Height	4.20	160	40	113	28
EM13	Hand Circumference	5.37	261	65	184	46
EM14	Hand Breadth	6.23	351	88	247	62
EM15	Hand Length	1.63	24	6	17	4
EM16	Hand Thickness	11.09	1113	278	784	196
EM17	Ankle Height	5.63	286	72	202	50

Measure		CV	Sample Size (DCC, SCE Two)			
			1% precision, 95% confidence	2% precision, 95% confidence	1% precision, 90% confidence	2% precision , 90% confiden ce
EM18	Foot Breadth, Horizontal	11.33	1161	290	818	204
EM19	Foot Length	7.51	510	127	359	90
EM20	Ball of Foot Length	8.84	706	177	497	124
EM21	Sitting Height	3.61	118	29	83	21
EM22	Acromion Height, Sitting	2.55	59	15	42	10
EM23	Bideltoid Breadth	1.21	13	3	9	2
EM24	Forearm-Forearm Breadth	4.98	224	56	158	39
EM25	Abdominal Extension Depth, Sitting	3.08	86	21	60	15
EM26	Hip Breadth, Sitting	4.36	172	43	121	30
EM27	Thigh Clearance	6.18	345	86	243	61
EM28	Knee Height, Sitting	4.49	182	45	128	32
EM29	Popliteal Height	5.28	252	63	177	44
EM30	Buttock-Knee Length	5.94	319	80	225	56
EM31	Buttock-Popliteal Length	7.53	513	128	361	90

Table G-5: Sample Size Calculations for Vehicle Crew (SCE Two)

Measure		CV	Sample Size (Vehicle Crew, SCE Two)			
			1% precision, 95% confidence	2% precision, 95% confidence	1% precision, 90% confidence	2% precision , 90% confiden ce
EM01	Stature	2.07	39	10	27	7
EM07	Chest Circumference	2.38	51	13	36	9
EM08	Chest Breadth	3.26	96	24	68	17
EM09	Chest Depth	3.49	110	28	78	19
EM10	Waist Circumference (Omphalion)	2.95	79	20	55	14
EM21	Sitting Height	2.99	81	20	57	14
EM23	Bideltoid Breadth	4.21	160	40	113	28
EM24	Forearm-Forearm Breadth	1.48	20	5	14	3
EM25	Abdominal Extension Depth, Sitting	6.43	374	94	264	66

Appendix H Initial and Redress Comparisons

Table H-1: Initial and Re-dress Condition Comparison: DCC (SCE One)

Measure		DCC (SCE One)							
		MALE				FEMALE			
		PECCF (mm)		Difference		PECCF (mm)		Difference	
		Initial	Re-dress	%	mm	Initial	Re-dress	%	mm
EM01	Stature	71	68	**4**	**3**	70	69	**1**	**1**
EM06	Acromion Height	53	46	**13**	**7**	57	53	**7**	**4**
EM07	Chest Circumference	418	412	**1**	**6**	471	462	**2**	**9**
EM08	Chest Breadth	12	13	**8**	**1**	24	20	**17**	**4**
EM09	Chest Depth	251	251	**0**	**0**	236	250	**6**	**14**
EM10	Waist Circumference (Omphalion)	660	668	**1**	**8**	665	681	**2**	**16**
EM11	Buttock Circumference	47	41	**13**	**6**	61	62	**2**	**1**
EM12	Crotch Height	-36	-31	**14**	**5**	-20	-16	**20**	**4**
EM13	Hand Circumference	24	21	**13**	**3**	27	27	**0**	**0**
EM14	Hand Breadth	6	6	**0**	**0**	5	4	**20**	**1**
EM15	Hand Length	10	10	**0**	**0**	9	11	**22**	**2**
EM16	Hand Thickness	4	5	**25**	**1**	6	7	**17**	**1**
EM17	Ankle Height	39	44	**13**	**5**	-	-	**-**	**-**
EM18	Foot Breadth, Horizontal	9	10	**11**	**1**	9	8	**11**	**1**
EM19	Foot Length	45	41	**9**	**4**	36	34	**6**	**2**
EM20	Ball of Foot Length	9	12	**33**	**3**	11	11	**0**	**0**
EM21	Sitting Height	31	26	**16**	**5**	30	31	**3**	**1**
EM22	Acromion Height, Sitting	12	14	**17**	**2**	20	18	**10**	**2**
EM23	Bideltoid Breadth	63	69	**10**	**6**	98	96	**2**	**2**
EM24	Forearm-Forearm Breadth	156	147	**6**	**9**	183	190	**4**	**7**
EM25	Abdominal Extension Depth, Sitting	266	267	**0**	**1**	263	274	**4**	**11**
EM26	Hip Breadth, Sitting	15	20	**33**	**5**	27	35	**30**	**8**
EM27	Thigh Clearance	17	20	**18**	**3**	16	15	**6**	**1**
EM28	Knee Height, Sitting	73	71	**3**	**2**	73	72	**1**	**1**
EM29	Popliteal Height	34	25	**27**	**9**	43	36	**16**	**7**
EM30	Buttock-Knee Length	-	-	**-**	**-**	21	23	**10**	**2**
EM31	Buttock-Popliteal Length	9	7	**22**	**2**	-13	-5	**62**	**8**

Table H-2: Initial and Re-dress Condition Comparison: Vehicle Crew (SCE One)

Measure		Vehicle Crew (SCE One)							
		MALE				FEMALE			
		PECCF (mm)		Difference		PECCF (mm)		Difference	
		Initial	Re-dress	%	mm	Initial	Re-dress	%	mm
EM01	Stature	69	66	**4**	**3**	62	66	**7**	**4**
EM07	Chest Circumference	154	143	**7**	**11**	186	182	**2**	**4**
EM08	Chest Breadth	17	14	**18**	**3**	18	13	**28**	**5**
EM09	Chest Depth	79	74	**6**	**5**	41	45	**10**	**4**
EM10	Waist Circumference (Omphalion)	379	367	**3**	**12**	358	369	**3**	**11**

Measure		Vehicle Crew (SCE One)							
		MALE				FEMALE			
		PECCF (mm)		Difference		PECCF (mm)		Difference	
		Initial	Re-dress	%	mm	Initial	Re-dress	%	mm
EM21	Sitting Height	33	20	**39**	**13**	26	25	**4**	**1**
EM25	Bideltoid Breadth	36	41	**14**	**5**	67	63	**6**	**4**
EM26	Forearm-Forearm Breadth	110	98	**11**	**12**	125	138	**10**	**13**
EM28	Abdominal Extension Depth, Sitting	80	79	**1**	**1**	92	104	**13**	**12**

Table H-3: Initial and Re-dress Condition Comparison: DCC (SCE Two)

Measure		DCC (SCE Two)			
		MALE			
		PECCF (mm)		Difference	
		Initial	Redress	%	mm
EM01	Stature	70	68	**3**	**2**
EM06	Acromion Height	44	33	**25**	**11**
EM07	Chest Circumference	427	348	**19**	**79**
EM08	Chest Breadth	25	32	**28**	**7**
EM09	Chest Depth	243	231	**5**	**12**
EM10	Waist Circumference (Omphalion)	676	672	**1**	**4**
EM11	Buttock Circumference	101	104	**3**	**3**
EM12	Crotch Height	-94	-80	**15**	**14**
EM13	Hand Circumference	16	18	**13**	**2**
EM14	Hand Breadth	5	5	**0**	**0**
EM15	Hand Length	6	4	**33**	**2**
EM16	Hand Thickness	3	5	**67**	**2**
EM21	Sitting Height	31	28	**10**	**3**
EM22	Acromion Height, Sitting	-1	-1	**0**	**0**
EM23	Bideltoid Breadth	95	102	**7**	**7**
EM24	Forearm-Forearm Breadth	196	209	**6**	**13**
EM25	Abdominal Extension Depth, Sitting	272	224	**18**	**48**
EM26	Hip Breadth, Sitting	39	39	**0**	**0**
EM27	Thigh Clearance	20	22	**10**	**2**
EM28	Knee Height, Sitting	73	77	**6**	**4**
EM29	Popliteal Height	26	24	**8**	**2**
EM30	Buttock-Knee Length	44	41	**7**	**3**
EM31	Buttock-Popliteal Length	4	5	**25**	**1**

Table H-4: Initial and Re-dress Condition Comparison: Vehicle Crew (SCE Two)

Measure		SCE Two: DCC			
		MALE			
		PECCF (mm)		Difference	
		Initial	Redress	%	mm
EM01	Stature	71	64	**10**	**8**
EM07	Chest Circumference	169	167	**1**	**2**
EM08	Chest Breadth	14	12	**14**	**2**
EM09	Chest Depth	80	75	**6**	**5**
EM10	Waist Circumference (Omphalion)	389	391	**1**	**2**
EM21	Sitting Height	36	37	**3**	**1**
EM23	Bideltoid Breadth	79	82	**4**	**3**
EM24	Forearm-Forearm Breadth	156	163	**5**	**7**
EM25	Abdominal Extension Depth, Sitting	91	89	**2**	**2**

Appendix I Clothing and Equipment Measures

Table 11: Comparison of equipment measures to survey PECCFs

Measure	Equipment	Measurement (mm)	Increase (mm)	PECCF (mm)	Difference	
					(mm)	(%)
EM01 Stature	*Can't identify helmet increase without encumbered measure*					
EM02 Weight	-	-	-	-	-	
EM03 Head Circumference	*Can't identify helmet increase without encumbered measure*					
EM04 Head Breadth	*Can't identify helmet increase without encumbered measure*					
EM05 Head Length	*Can't identify helmet increase without encumbered measure*					
EM06 Acromion height	Crye Shirt (material)	5	30	57	**-27**	**-91**
	Boot (heel)	25				
EM07 Chest Circumference	*Can't add equipment to circumference measurement*					
EM08 Chest Breadth	Crye Shirt (material)	5	10	24	**-14**	**-139**
	Crye Shirt (material)	5				
EM09 Chest Depth	TBAS II (back/top)	45	266	251	**15**	**6**
	TBAS II (front/top)	40				
	Camelbak (top)	96				
	Grenade	75				
	Crye Shirt (material)	5				
	Crye Shirt (material)	5				
EM10 Waist Circumference (Omphalion)	*Can't add equipment to circumference measurement*					
EM11 Buttock Circumference	*Can't add equipment to circumference measurement*					
EM12 Crotch Height	*Can't identify crotch height without pants being worn*					
EM13 Hand Circumference	CWC Gloves	5	16	27	**-11**	**69**
EM14 Hand Breadth	CWC Gloves	5	5	6	**-1**	**-24**
EM15 Hand Length	CWC Gloves	5	5	10	**-5**	**-98**
EM16 Hand Thickness	CWC Gloves	5	5	6	**-1**	**-26.67**
EM17 Ankle Height	Boot (heel)	34	39	46	**-7**	**-18.55**
	Sock	5				
EM18 Foot Breadth, Horizontal	*Can't identify foot breadth without pants being worn*					
EM19 Foot Length	*Can't identify foot length without pants being worn*					
EM20 Ball of Foot Length	*Can't identify ball of foot length without pants being worn*					
EM21 Sitting Height	*Can't identify sitting height (helmet increase) without encumbered measure*					

Measure	Equipment	Measurement (mm)	Increase (mm)	PECCF (mm)	Difference (mm)	Difference (%)
EM22 Acromion Height, Sitting	Crye Pants (buttock material)	6	6	20	**-14**	**-237**
EM23 Bideltoid Breadth	Crye Shirt (bicep pocket)	19	38	77	**-39**	**-102**
	Crye Shirt (bicep pocket)	19				
EM24 Forearm-Forearm Breadth	TBAS II (side)	22	104	183	**-79**	**-76**
	TBAS II (side)	22				
	Med Pouch	30				
	Admin Pouch	30				
EM25 Abdominal Extension Depth, Sitting	TBAS II (back/bottom)	50	226	266	**-40**	**-18**
	TBAS II (front/bottom)	48				
	Camelbak (top)	96				
	Magazine	32				
EM26 Hip Breadth, Sitting	CWC Pants	6	24	27	**-3**	**-14**
	CWC Pants	6				
	CWC Pants	6				
	CWC Pants	6				
EM27 Thigh Clearance	CWC Pants	6	12	17	**-5**	**-38**
	CWC Pants	6				
EM28 Knee Height, Sitting	*Can't identify knee height without encumbered measure*					
EM29 Popliteal Height	*Can't identify knee height without encumbered measure*					
EM30 Buttock-Knee Length	Crye Pants (buttock material)	6	12	21	**-9**	**-71**
	Crye Pants (knee pads)	6				
EM31 Buttock-Popliteal Length	Crye Pants (buttock material)	6	6	9	**-3**	**-50**

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19. ABSTRACT

The Australian Warfighter Anthropometry Survey (AWAS), as per traditional anthropometric protocol, gathered data from semi-nude subjects. It is important, when required, to apply a clothing correction factor to these semi-nude statistics to ensure a more realistic representation of the encumbered human. Data from a meta-analysis of current personal equipment and clothing corrections (PECCFs) data identified the need for an encumbered anthropometric survey applicable to the ADF. The aim of the pilot survey was two-fold. Firstly, to provide interim PECCFs for use in design projects and secondly, to develop, test and refine a reliable, valid methodology for use in future surveys. The methodology proved to be largely successful with the majority of measures providing reliable results although there were limitations imposed by a small sample size. A number of recommendations were produced relating to further areas of work to further analyse and refine future surveys.

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